

## Chapter 5

### Processing Digital Imagery

**5-1 Introduction.** Image processing in the context of remote sensing refers to the management of digital images, usually satellite or digital aerial photographs. Image processing includes the display, analysis, and manipulation of digital image computer files. The derived product is typically an enhanced image or a map with accompanying statistics and metadata. An image analyst relies on knowledge in the physical and natural sciences for aerial view interpretation combined with the knowledge of the nature of the digital data (see Chapter 2). This chapter will explore the basic methods employed in image processing. Many of these processes rely on concepts included in the fields of geography, physical sciences, and analytical statistics.

### 5-2 Image Processing Software.

*a.* Imaging software facilitates the processing of digital images and allows for the manipulation of vast amounts of data in the file. There are numerous software programs available for image processing and image correction (atmospheric and geometric corrections). A few programs are available as share-ware and can be downloaded from the internet. Other programs are available through commercial vendors who may provide a free trial of the software. Some vendors also provide a tutorial package for testing the software.

*b.* The various programs available have many similar processing functions. There may be minor differences in the program interface, terminology, metadata files (see below), and types of files it can read (indicated by the file extension). There can be a broad range in cost. Be aware of the hardware requirements and limitations needed for running such programs. An on-line search for remote sensing software is recommended to acquire pertinent information concerning the individual programs.

### 5-3 Metadata.

*a.* Metadata is simply ancillary information about the characteristics of the data; in other words, it is data about the data. It describes important elements concerning the acquisition of the data as well as any post-processing that may have been performed on the data. Metadata is typically a digital file that accompanies the image file or it can be a hardcopy of information about the image. Metadata files document the source (i.e., Landsat, SPOT, etc.), date and time, projection, precision, accuracy, and resolution. It is the responsibility of the vendor and the user to document any changes that have been applied to the data. Without this information the data could be rendered useless.

*b.* Depending on the information needed for a project, the metadata can be an invaluable source of information about the scene. For example, if a project centers on change detection, it will be critical to know the dates in which the image data were collected. Numerous agencies have worked toward standardizing the documentation of metadata in an effort to simplify the process for both vendors and users. The Army Corps of Engineers follows the Federal Geographic Data Committee (FGDC) standards for metadata

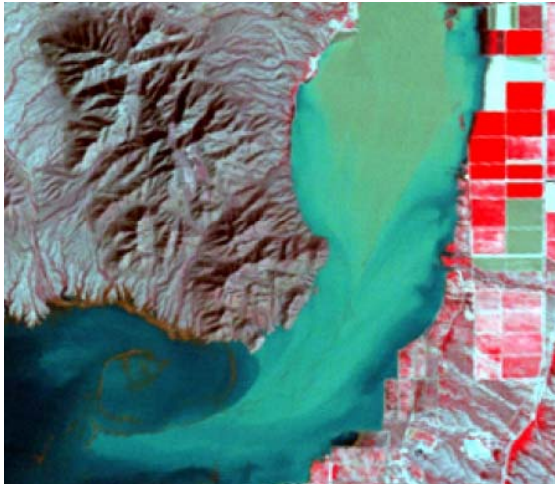
(go to <http://geology.usgs.gov/tools/metadata/standard/metadata.html>). The importance of metadata cannot be overemphasized.

**5-4 Viewing the Image.** Image files are typically displayed as either a gray scale or a color composite (see Chapter 2). When loading a gray scale image, the user must choose one band for display. Color composites allow three bands of wavelengths to be displayed at one time. Depending on the software, users may be able to set a default band/color composite or designate the band/color combination during image loading.

**5-5 Band/Color Composite.** A useful initial composite (as seen in Figure 5-1a) for a Landsat TM image is Bands 3, 2, 1 (RGB). This will place band 3 in the red plane, band 2 in the green plane, and band 1 in the blue plane. The resultant image is termed a true-color composite and it will resemble the colors one would observe in a color photograph. Another useful composite is Bands 4, 3, 2 (R, G, B), known as a false-color composite (Figure 5-1b). Similar to a false-color infrared photograph, this composite displays features with color and contrast that differ from those observed in nature. For instance, healthy vegetation will be highlighted by band 4 and will therefore appear red. Water and roads may appear nearly black.



a. True-color Landsat TM composite 3, 2, 1 (RGB respectively).



b. False color composite 4, 3, 2.

Figure 5-1. Figure 5-1a is scene in which water, sediment, and land surfaces appear bright. Figure 5-1b is a composite that highlights healthy vegetation (shown in red); water with little sediment appears black. Images developed for USACE Prospect #196 (2002).

**5-6 Information About the Image.** Once the image is displayed it is a good idea to become familiar with the characteristics of the data file. This information may be found in a separate metadata file or as a header file embedded with the image file. Be sure to note the pixel size, the sensor type, data, the projection, and the datum.

### 5-7 Datum.

a. A geographic datum is a spherical or ellipsoidal model used to reference a coordinate system. Datums approximate the shape and topography of the Earth. Numerous

datums have evolved, each developed by the measurement of different aspects of the Earth's surface. Models are occasionally updated with the use of new technologies. For example, in 1984 satellites carrying GPS (global position systems) refined the World Geodetic System 1927 (WGS-27); the updated datum is referred to as WGS-84 (World Geodetic System-1984). Satellite data collected prior to 1984 may have coordinates linked to the WGS-27 datum. Georeferencing coordinates to the wrong datum may result in large positional errors. When working with multiple images, it is therefore important to match the datum for each image.

*b.* Image processing software provide different datums and will allow users to convert from one datum to another. To learn more about geodetic datums go to [http://www.ngs.noaa.gov/PUBS\\_LIB/Geodesy4Layman/geo4lay.pdf](http://www.ngs.noaa.gov/PUBS_LIB/Geodesy4Layman/geo4lay.pdf).

## **5-8 Image Projections.**

*a.* Many projects require precise location information from an image as well as geocoding. To achieve these, the data must be georeferenced, or projected into a standard coordinate system such as Universal Transverse Mercator (UTM), Albers Conical Equal Area, or a State Plane system. There are a number of possible projections to choose from, and a majority of the projections are available through image processing software. Most software can project data from one map projection to another, as well as unprojected data. The latter is known as rectification. Rectification is the process of fitting the grid of pixels displayed in an image to the map coordinate system grid (see Paragraph 5-14).

*b.* The familiar latitude and longitude (Lat/Long) is a coordinate system that is applied to the globe (Figure 5-2). These lines are measured in degrees, minutes, and seconds (designated by °, ', and " respectively). The value of one degree is given as 60 minutes; one minute is equivalent to 60 seconds ( $1^{\circ} = 60'$ ;  $1' = 60''$ ). It is customary to present the latitude value before the longitude value.

**5-9 Latitude.** Latitude lines, also known as the parallels or parallel lines, are perpendicular to the longitude lines and encircle the girth of the globe. They are parallel to one another, and therefore never intersect. The largest circular cross-section of the globe is at the equator. For this reason the origin of latitude is at the equator. Latitude values increase north and south away from the equator. The north or south direction must be reported when sighting a coordinate, i.e., 45°N. Latitude values range from 0 to 90°, therefore the maximum value for latitude is 90°. The geographic North Pole is at 90°N while the geographic South Pole is at 90°S

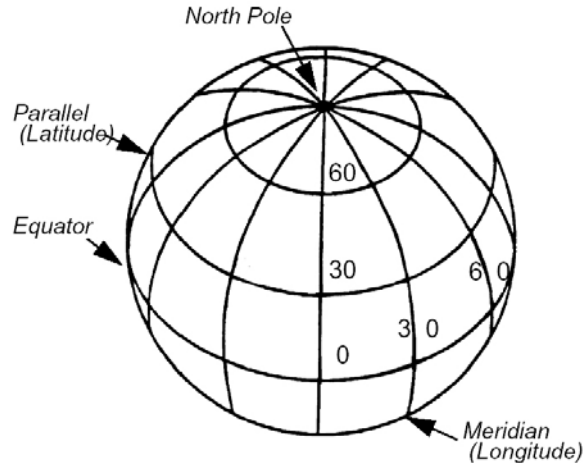


Figure 5-2. Geographic projection.

**5-10 Longitude.** The lines of longitude pass through the poles, originating at Greenwich, England ( $0^\circ$  longitude) and terminating in the Pacific ( $180^\circ$ ). Because the Earth's spheroidal shape approximates a circle, its degree measurement can be given as  $360^\circ$ . Therefore, to travel half way around the world one must move  $180^\circ$ . The degrees of longitude increase to the east and west, away from the origin. The coordinate value for longitude is given by the degree number and the direction from the origin, i.e.,  $80^\circ\text{W}$  or  $130^\circ\text{E}$ . **Note:**  $180^\circ\text{W}$  and  $180^\circ\text{E}$  share the same line of longitude.

**5-11 Latitude/Longitude Computer Entry.** Software cannot interpret the north/south or east/west terms used in any coordinate system. Negative numbers must be used when designating latitude coordinates south of the Equator or longitude values west of Greenwich. This means that for any location in North America the latitude coordinate will be positive and the longitude coordinate will be given as a negative number. Coordinates north of the equator and east of Greenwich will be positive. It is usually not necessary to add the positive sign (+) as the default values in most software are positive numbers. The coordinates for Niagara Fall, New York are  $43^\circ 6' \text{N}$ ,  $79^\circ 57' \text{W}$ ; these values would be recorded as decimal degrees in the computer as  $43.1^\circ$ ,  $-79.95^\circ$ . Notice that the negative sign replaces the "W" and minutes were converted to decimal degrees (see example problem below). **Important Note:** Coordinates west of Greenwich England are entered into the computer as a negative value.

**5-12 Transferring Latitude/Longitude to a Map.** Satellite images and aerial photographs have inherent distortions owing to the projection of the Earth's three-dimensional surface onto two-dimensional plane (paper or computer monitor). When the Latitude/Longitude coordinate system is projected onto a paper plane, there are tremendous distortions. These distortions lead to problems with area, scale, distance, and direction. To alleviate this problem cartographers have developed alternative map projections.

**Problem:** The Golden Gate Bridge is located at latitude  $37^{\circ} 49' 11''$  N, and longitude  $122^{\circ} 28' 40''$  W. Convert degrees, minutes, and seconds (known as sexagesimal system) to decimal degrees and format the value for computer entry.

**Solution:** The whole units of degrees will remain the same (i.e., the value will begin with 37). Minutes and seconds must be converted to degrees and added to the whole number of degrees.

**Calculation: Latitude:**  $37^{\circ} = 37^{\circ}$   
 $49' = 49'(1^{\circ}/60') = 0.82^{\circ}$   
 $11'' = 11''(1'/60'')(1^{\circ}/60') = 0.003^{\circ}$   
 $37^{\circ} + 0.82^{\circ} + 0.003^{\circ} = 37.82^{\circ}$   
 $37^{\circ} 49' 11'' \text{ N} = 37.82^{\circ}$

**Longitude:**  $122^{\circ} = 122^{\circ}$   
 $28' = 28'(1^{\circ}/60') = 0.47^{\circ}$   
 $40'' = 40''(1'/60'')(1^{\circ}/60') = 0.01^{\circ}$   
 $122^{\circ} + 0.47^{\circ} + 0.01^{\circ} = 122.48^{\circ}$   
 $122^{\circ} 28' 40'' \text{ W} = 122.48^{\circ}$

**Answer:**  $37.82^{\circ}, -122.48^{\circ}$

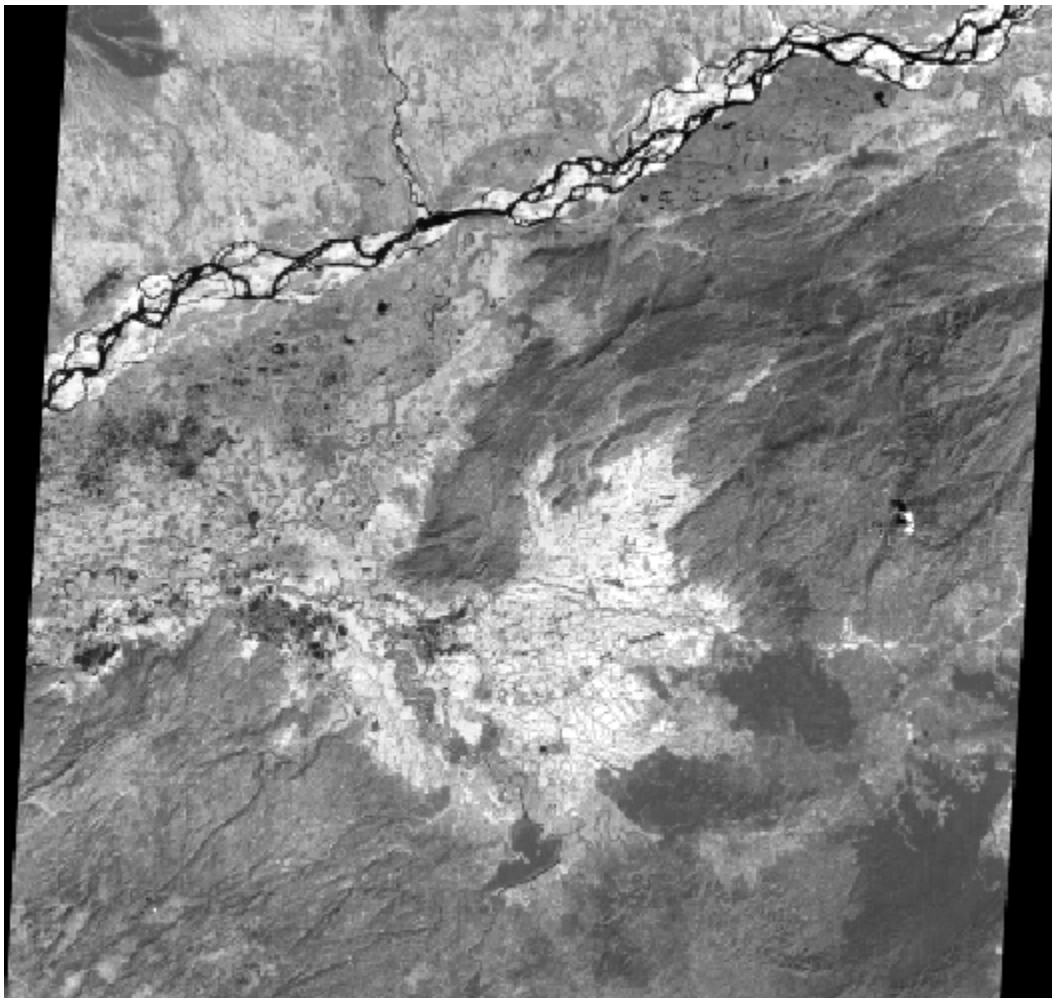
### 5-13 Map Projections.

a. Map projections are attempts to render the three-dimensional surface of the earth onto a planar surface. Projections are designed to minimize distortion while preserving the accuracy of the image elements important to the user. Categories of projections are constructed from cylindrical, conic, and azimuthal planes, as well as a variety of other techniques. Each type of projection preserves and distorts different properties of a map projection. The most commonly used projections are Geographical (Lat/Lon), Universal Transverse Mercator (UTM), and individual State Plane systems. Geographic (Lat/Lon) is the projection of latitude and longitude with the use of a cylindrical plane tangent to the equator. This type of projection creates great amounts of distortion away from the poles (this explains why Greenland will appear larger than the US on some maps).

*b.* The best projection and datum to use will depend on the projection of accompanying data files, location of the origin of the data set, and limitations on acceptable projection distortion.

#### **5-14 Rectification.**

*a.* Image data commonly need to be rectified to a standard projection and datum. Rectification is a procedure that distorts the grid of image pixels onto a known projection and datum. The goal in rectification is to create a faithful representation of the scene in terms of position and radiance. Rectification is performed when the data are unprojected, needs to be reprojected, or when geometric corrections are necessary. If the analysis does not require the data to be compared or overlain onto other data, corrections and projections may not be necessary. See Figure 5-3 for an example of a rectified image.



**Figure 5-3.** A rectified image typically will appear skewed. The rectification correction has rubber-sheeted the pixels to their geographically correct position. This geometric correction seemingly tilts the image leaving black margins where there are no data.

*b.* There are two commonly used rectification methods for projecting data. Image data can be rectified by registering the data to another image that has been projected or by assigning coordinates to the unprojected image from a paper or digital map. The following sections detail these methods. A third method uses newly collected GIS reference points or in-house GIS data such as road, river, or other Civil Works GIS information.

**5-15 Image to Map Rectification.** Unprojected images can be warped into projections by creating a mathematical relationship between select features on an image and the same feature on a map (a USGS map for instance). The mathematical relationship is then applied to all remaining pixels, which warps the image into a projection.

**5-16 Ground Control Points (GCPs).** The procedure requires the use of prominent features that exist on both the map and the image. These features are commonly referred to as ground control points or GCPs. GCPs are well-defined features such as sharp bends in a river or intersections in roads or airports. Figure 5-4 illustrates the selection of GCPs in the image-to-image rectification process; this process is similar to that used in image to map rectification. The minimum number of GCPs necessary to calculate the transformation depends upon the order of the transformation. The order of transformation can be set within the software as 1<sup>st</sup>, 2<sup>nd</sup>, or 3<sup>rd</sup> order polynomial transformation. The following equation (5-1) identifies the number of GCPs required to calculate the transformation. If the minimum number is not met, an error message should inform the user to select additional points. Using more than the minimum number of GCPs is recommended.

$$\frac{(t+1)(t+2)}{2} = \text{minimum number of GCPs} \quad 5-1$$

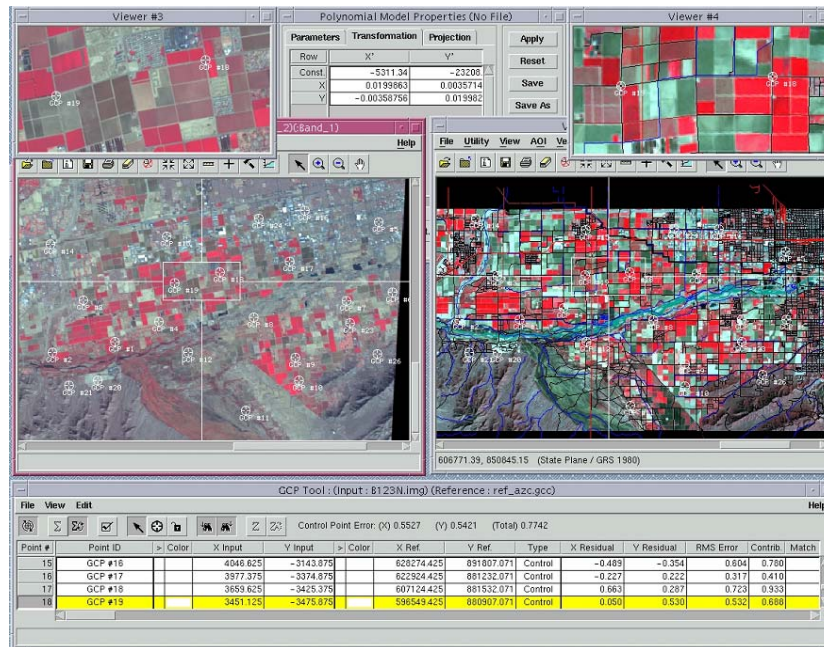
where  $t$  = order of transformation (1<sup>st</sup>, 2<sup>nd</sup>, or 3<sup>rd</sup>).

*a.* To begin the procedure, locate and record the coordinate position of 10 to 12 features found on the map and in the image. Bringing a digital map into the software program will simplify coordinate determination with the use of a coordinate value tool. When using a paper map, measure feature positions as accurately as possible, and note the map coordinate system used. The type of coordinate system used must be entered into the software; this will be the projection that will be applied to the image. Once projected, the image can be easily projected into a different map projection.

*b.* After locating a sufficient number of features (and GCPs) on the map, find the same feature on the image and assign the coordinate value to that pixel. Zooming in to choose the precise location (pixel) will lower the error. When selecting GCPs, it is best to choose points from across the image, balancing the distribution as much as possible; this will increase the positional accuracy. Once the GCP pixels have been selected and given a coordinate value, the software will interpolate and transform the remaining pixels into position.

**5-17 Positional Error.** The program generates a least squares or “Root Mean Square” (RMS) estimation of the positional accuracy of the mathematical transforma-

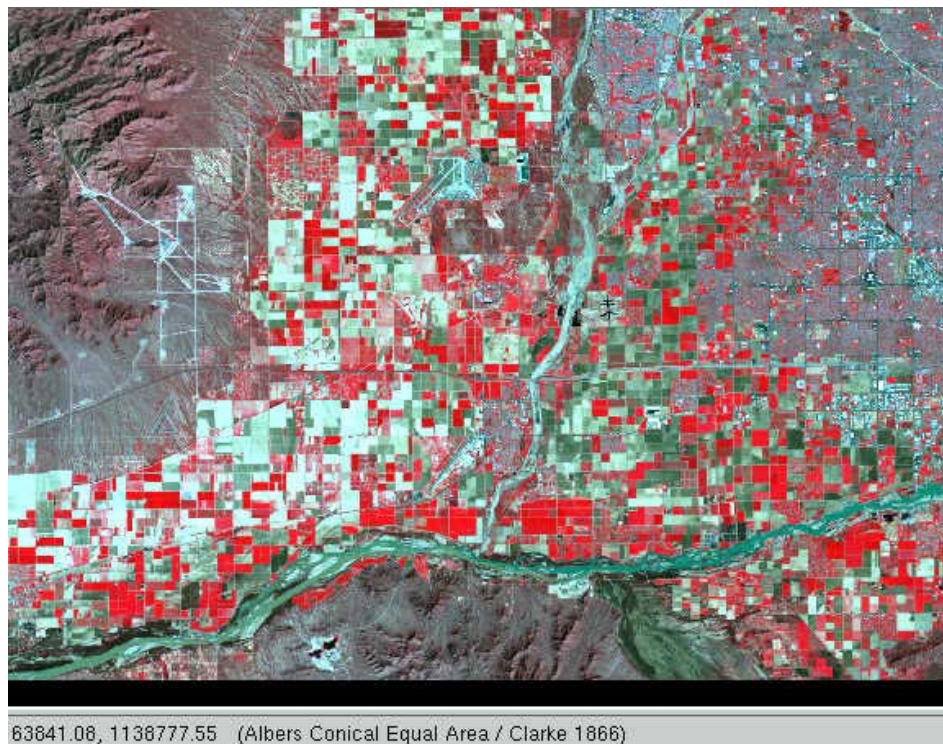
tion. The root mean square estimates the level of error in the transformation. The estimate will not be calculated until three or four GCPs have been entered. Initial estimates will be high, and should decrease as more GCPs are added to the image. A root mean square below 1.0 is a reasonable level of accuracy. If the RMS is higher than 1.0, simply reposition GCPs with high individual errors or delete them and reselect new GCPs. With an error less than 1.0 the image is ready to be warped to the projection and saved.



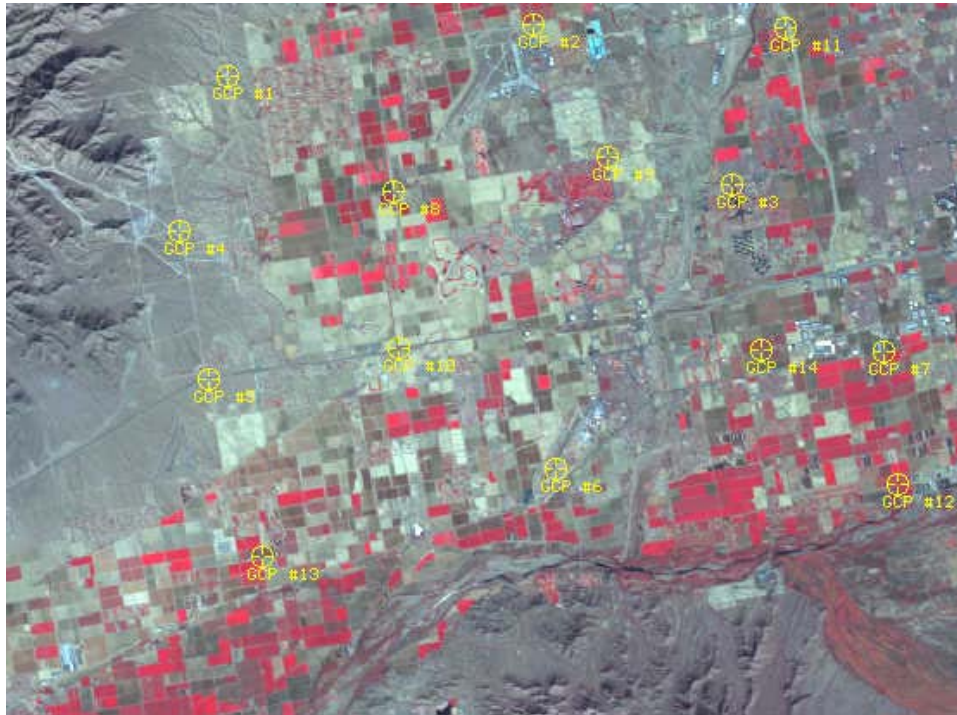
**a. The scene appearance of the GCP selection module may look similar to this scene capture. Each segment of the function is presented individually below.**



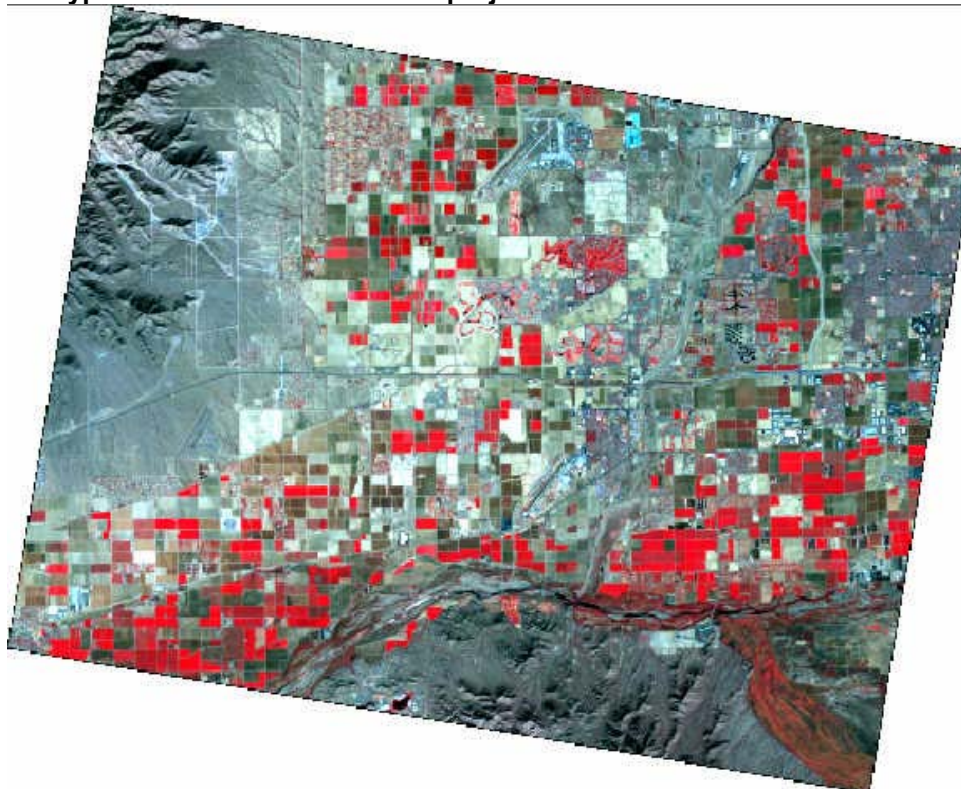
**b. This scene represents the original, unprojected data file**



**c. This geo-registered image is used to match sites within the unprojected data file. Projected images such as this are often available on-line.**



d. GCPs are located by matching image features between the projected and unprojected image. Notice the balanced spatial distribution of the GCPs; this type of distribution lowers the projection error.



e. Unprojected data are then warped to the GCP positions. This results in a skewed image. The image is now projected onto a coordinate system and is now ready for GIS processing.

Point #	Point ID	> Color	X Input	Y Input	> Color	X Ref.	Y Ref.	Type	X Residual	Y Residual	RMS Error
1	GCP #1	> [Yellow]	1975.622	-2753.911	[Yellow]	49213.866	1161299.942	Control	1.234	1.972	2.326
2	GCP #2	[Yellow]	2655.250	-2637.750	[Yellow]	59543.625	1161310.875	Control	1.379	0.956	1.678
3	GCP #3	[Yellow]	3098.250	-2996.250	[Yellow]	65186.625	1154926.875	Control	-0.774	0.961	1.234
4	GCP #4	[Yellow]	1868.859	-3098.903	[Yellow]	46798.702	1156464.425	Control	1.623	1.324	2.094
5	GCP #5	[Yellow]	1931.464	-3429.864	[Yellow]	46894.946	1151387.293	Control	0.571	-1.450	1.558
6	GCP #6	[Yellow]	2703.750	-3629.250	[Yellow]	57822.011	1146542.026	Control	0.187	-0.572	0.602
7	GCP #7	[Yellow]	3435.150	-3369.297	[Yellow]	69283.500	1148578.500	Control	1.021	0.736	1.258
8	GCP #8	[Yellow]	2343.645	-3013.072	[Yellow]	53967.095	1156542.926	Control	-2.201	0.076	2.203
9	GCP #9	[Yellow]	2820.656	-2935.227	[Yellow]	61218.435	1156484.175	Control	-1.299	-1.320	1.852
10	GCP #10	[Yellow]	2355.239	-3363.377	[Yellow]	53271.130	1151353.348	Control	-3.162	0.435	3.192
11	GCP #11	[Yellow]	3216.509	-2647.033	[Yellow]	67765.742	1159693.500	Control	-1.119	-5.344	5.460
12	GCP #12	[Yellow]	3465.588	-3666.561	[Yellow]	68978.790	1144097.756	Control	-0.742	-0.866	1.140
13	GCP #13	[Yellow]	2052.654	-3828.383	[Yellow]	47701.592	1145192.371	Control	-0.153	-2.550	2.554
14	GCP #14	[Yellow]	3163.038	-3364.161	[Yellow]	65321.952	1149396.204	Control	3.435	5.641	6.605
15	GCP #15	> [Yellow]			> [Yellow]			Control			

f. RMS error for each GCP is recorded in a matrix spreadsheet. A total RMS error of 0.7742 is provided in the upper margin of Figure 5-4a.

Figure 5-4. GCP selection display modules.

**5-18 Project Image and Save.** The last procedure in rectification involves re-sampling the image using a “nearest neighbor” re-sampling technique. The software easily performs this process. Nearest neighbor re-sampling uses the value of the nearest pixel and extracts the value to the output, or re-sampled pixel. This re-sampling method preserves the digital number value (spectral value) of the original data. Additional re-sampling methods are bilinear interpolation and cubic convolution, which recalculate the spectral data. The image is projected subsequent to re-sampling, and the file is ready to be saved with a new name.

**Recommendation:** Naming altered data files and documenting procedures

Manipulating the data alters the original data file. It is therefore a good idea to save data files with different names after performing major alterations to the data. This practice creates reliable data backup files.

Because of the number of data files an analysis can create, it is best to clearly name the altered image files with the procedure name performed on the image (i.e., “TmSept01warped” indicates Thematic Mapper data collected September 2001, warped by user). Be sure to document your procedures and parameters used in a journal or a text file. Include the name of the altered file, changes applied to the data, the date, and other useful information.

## 5-19 Image to Image Rectification.

a. Images can also be rectified to a second projected digital image. The procedure is similar to that performed in image to map rectification. Simply locate common, identifiable features in both images, match the locations, and assign GCPs. Adjust GCPs until RMS error is less than 1.0. Enter the coordinate system that will be used and designate a re-sampling method (Figure 5-4).

b. Rectified images can easily be converted from one coordinate system to another. Projected images can readily be superimposed onto other projected data and used for georeferencing image features.

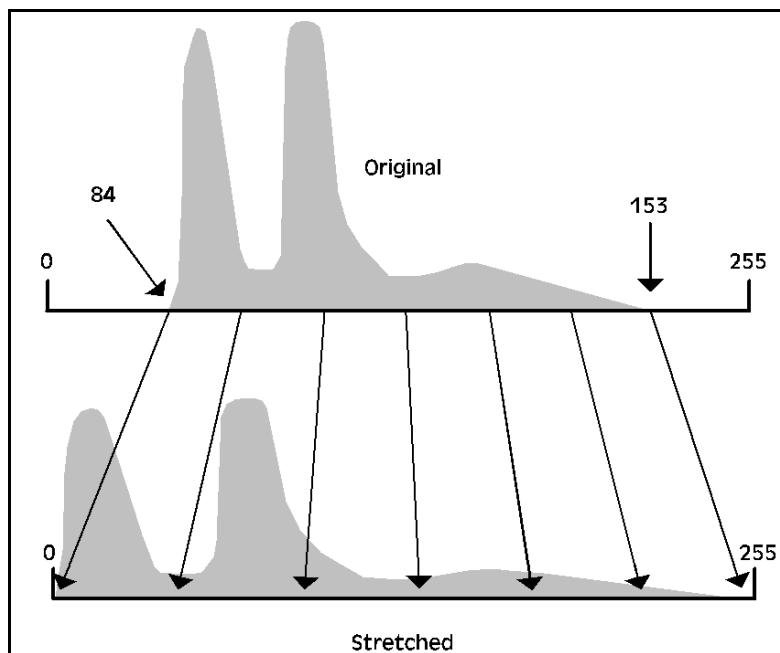
**5-20 Image Enhancement.** The major advantage of remote sensing data lies in the ability to visually evaluate the data for overall interpretation. An accurate visual interpretation may require modification of the output brightness of a pixel in an effort to improve image quality. Here are a number of methods used in image enhancement. This paragraph examines the operations of 1) contrast enhancement, 2) band ratio, 3) spatial filtering, and 4) principle components. The type of enhancement performed will depend on the appearance of the original scene and the goal of the interpretation.

### a. *Image Enhancement #1: Contrast Enhancement.*

(1) *Raw Image Data.* Raw satellite data are stored as multiple levels of brightness known as the digital number (DN). Paragraph 2-7a explained the relationship between the number of brightness levels and the size of the data storage. Data stored in an 8-bit data format maintain 256 levels of brightness. This means that the range in brightness will be 0 to 255; zero is assigned the lowest brightness level (black in gray- and color-scale images), while 255 is assigned the highest brightness value (white in gray scale or 100% of the pigment in a color scale). The list below summarizes the brightness ranges in a gray scale image.

0	=	black
50	=	dark gray
150	=	medium gray
200	=	light gray
255	=	white

(a) When a satellite image is projected, the direct one-to-one assignment of gray scale brightness to digital number values in the data set may not provide the best visual display (Figures 5-5 and 5-6). This will happen when a number of pixel values are clustered together. For instance, if 80% of the pixels displayed DNs ranging from 50–95, the image would appear dark with little contrast.



**Figure 5-5. A linear stretch involves identifying the minimum and maximum brightness values in the image histogram and applying a transformation to stretch this range to fill the full range across 0 to 255.**



**Figure 5-6. Contrast in an image before (left) and after (right) a linear contrast stretch. Taken from [http://rst.gsfc.nasa.gov/Sect1/Sect1\\_12a.html](http://rst.gsfc.nasa.gov/Sect1/Sect1_12a.html).**

(b) The raw data can be reassigned in a number of ways to improve the contrast needed to visually interpret the data. The technique of reassigning the pixel DN value is known as the image enhancement process. Image enhancement adds contrast to the data by stretching clustered DNs across the 0–255 range. If only a small part of the DN range is of interest, image enhancement can stretch those values and compress the end values to suppress their contrast. If a number of DNs are clustered on the 255 end of the range,

it is possible that a number of the pixels have DN's greater than 256. An image enhancement will decompress these values, thereby increasing their contrast.

## **Data Analysis**

### *Histograms*

Image processing software can chart the distribution of digital number values within a scene. The distribution of the brightness values is displayed as a histogram chart. The horizontal axis shows the spread of the digital numbers from 0 to the maximum DN value in the data set. The vertical axis shows the frequency or how many pixels in the scene each value has (Figure 5-7). The histogram allows an analyst to quickly access the type of distribution maintained by the data. Types of distribution may be normal, bimodal, or skewed (Figure 5-7). Histograms are particularly useful when images are enhanced.

### *Lookup Tables*

A lookup table (LUT) graphs the intensity of the input pixel value relative to the output brightness observed on the screen. The curve does not provide information about the frequency of brightness, instead it provides information regarding the range associated with the brightness levels. An image enhancement can be modeled on a lookup table to better evaluate the relationship between the unaltered raw data and the adjusted display data.

### *Scatter plots*

The correlation between bands can be seen in scatter plots generated by the software. The scatter plots graph the digital number value of one band relative to another (Figure 5-8). Bands that are highly correlated will produce plots with a linear relationship and little deviation from the line. Bands that are not well correlated will lack a linear relationship. Digital number values will cluster or span the chart randomly. Scatter plots allow for a quick assessment of the usefulness of particular band combinations.

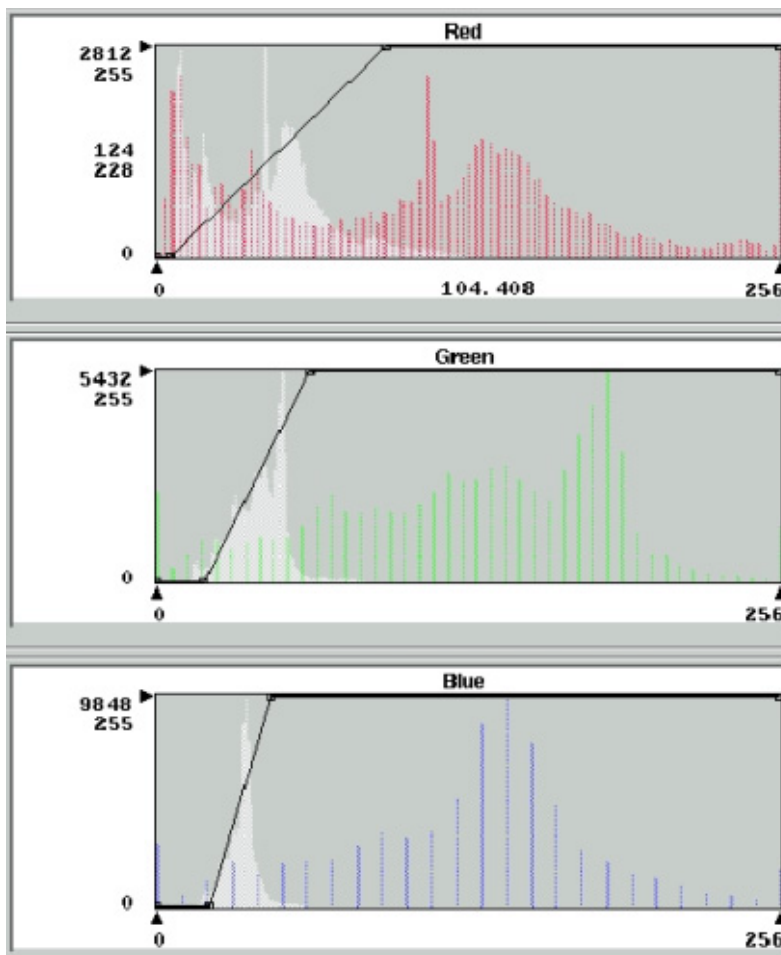
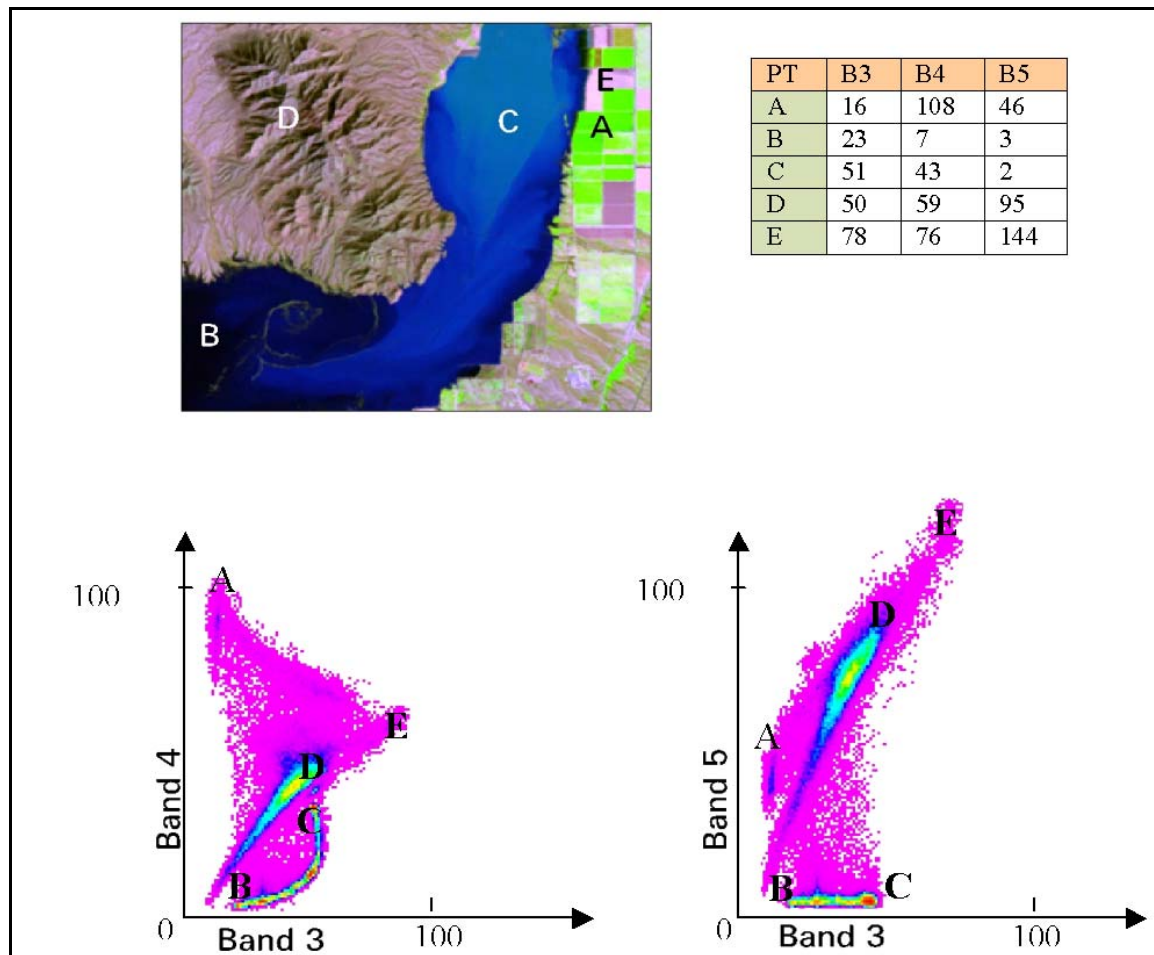


Figure 5-7. Pixel population and distribution across the 0 to 255 digital number range. All three plots show the pixel distribution before and after a linear stretch function (white denotes pre-stretch distribution and colored elements denote stretched pixel distribution). The stretched histogram shows gaps between the single values due to the discrete number of pixel values in the data set. The top histogram (red) has a bimodal distribution. The middle (green) maintains a skewed distribution, while the last histogram (blue) reveals a normal distribution. The solid black line superimposed in each image indicates the maximum and minimum DN value that is stretched across the entire range. Notice the straight lines that join the linear segment. Image taken from Prospect (2002 and 2003).



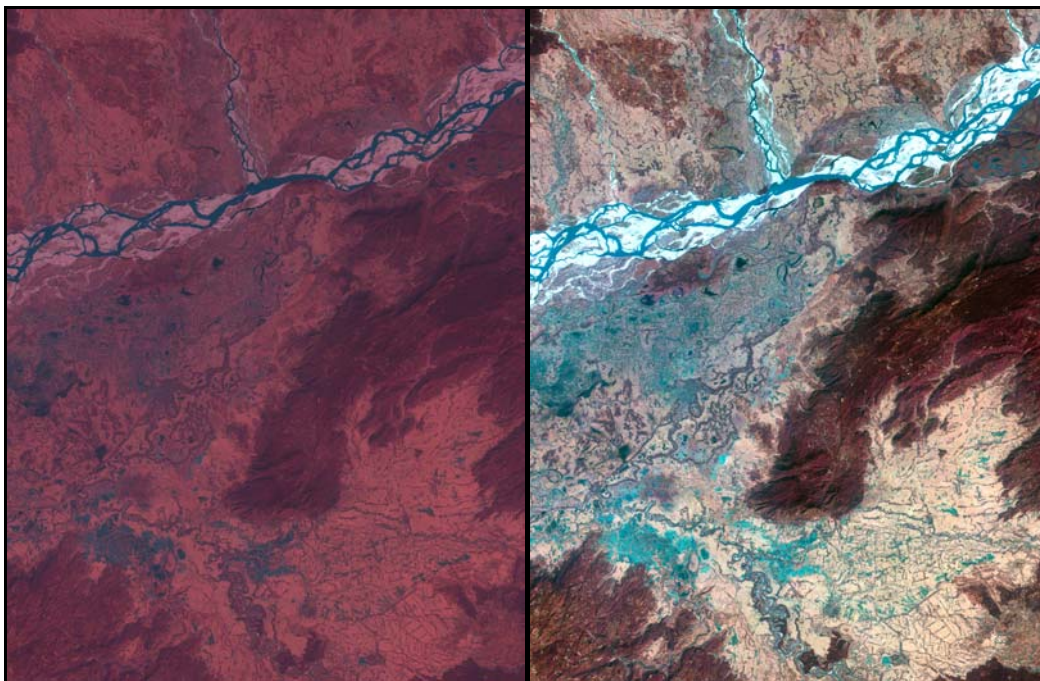
**Figure 5-8. Landsat TM band 345 RGB color composite with accompanying image scatter plots.** The scatter plots map band 3 relative to bands 4 and 5 onto a feature space graph. The data points in the plot are color coded to display pixel population. The table provides the pixel count for five image features in band 3, 4, and 5. A is agricultural land, B is deep (partially clear) water, C is sediment laden water, D is undeveloped land, E fallow fields. Image developed for Prospect (2002 and 2003).

(2) *Enhancing Pixel Digital Number Values.* Images can enhance or stretch the visual display of an image by setting up a different relationship between the DN and the brightness level. The enhancement relationship created will depend on the distribution of pixel DN values and which features need enhancement. The enhancement can be applied to both gray- and color-scale images.

(3) *Contrast Enhancement Techniques.* The histogram chart and lookup table are useful tools in image enhancement. Enhancement stretching involves a variety of techniques, including contrast stretching, histogram equalization, logarithmic enhancement, and manual enhancement. These methods assume the image has a full range of intensity (from 0–255 in 8-bit data) to display the maximum contrast.

(4) *Linear Contrast Stretching.* Contrast stretching takes an image with clustered intensity values and stretches its values linearly over the 0–255 range. Pixels in a very

bright scene will have a histogram with high intensity values, while a dark scene will have low intensity values (Figure 5-9). The low contrast that results from this type of DN distribution can be adjusted with contrast stretching, a linear enhancement function performed by image processing software. The method can be monitored with the use of a histogram display generated by the program.



**Figure 5-9. Unenhanced satellite data on left. After a default stretch, image contrast is increased as the digital number values are distributed over the 0–255 color range. The resulting scene (shown on the right) has a higher contrast.**

(a) Contrast stretching allocates the minimum and maximum input values to 0 and 255, respectively. The process assigns a gray level 0 to a selected low DN value, chosen by the user. All DNs smaller than this value are assigned 0 as well, grouping the low input values together. Gray level 255 is similarly assigned to a selected high DN value and all higher DN values. Intermediate gray levels are assigned to intermediate DN values proportionally. The resulting graph looks like a straight line (shown in Figure 5-7 as the black solid-line plot superimposed onto the three DN histograms), while the corresponding histogram will distribute values across the range, leaving an increase to the image contrast (Figure 5-9). The stretched histogram shows gaps between the single values due to the discrete number of pixel values in the data set (Figure 5-7). The proportional brightness gives a more accurate appearance to the image data, and will better accommodate visual interpretation.

(b) The linear enhancement can be greatly affected by a random error that is particularly high or low in brightness values. For this reason, a non-linear stretch is sometimes preferred. In non-linear stretches, such as histogram equalization and logarithmic enhancement, brightness values are reassigned using an algorithm that exaggerates contrast in the range of brightness values most common in that image.

(5) *Histogram Equalization*. Low contrast can also occur when values are spread across the entire range. The low contrast is a result of tight clustering of pixels in one area (Figure 5-10a). Because some pixel values span the intensity range it is not possible to apply the contrast linear stretch. In Figure 5-10a, the high peak on the low intensity end of the histogram indicates that a narrow range of DN values is used by a large number of pixels. This explains why the image appears dark despite the span of values across the full 0–255 range.

(a) Histogram equalization evenly distributes the pixel values over the entire intensity range (see steps below). The pixels in a scene are numerically arranged according to their DN values and divided into 255 equal-sized groups. The lowest level is assigned a gray level of zero, the next group is assigned DN 1, ..., the highest group is assigned gray level 255. If a single DN value has more pixels than a group, gray levels will be skipped. This produces gaps in the histogram distribution. The resultant shape of the graph will depend on the frequency of the scene.

(b) This method generally reduces the peaks in the histogram, resulting in a flatter or lower curve (Figure 5-10b). The histogram equalization method tends to enhance distinctions within the darkest and brightest pixels, sacrificing distinctions in mid-gray. This process will result in an overall increase in image contrast (Figure 5-10b).

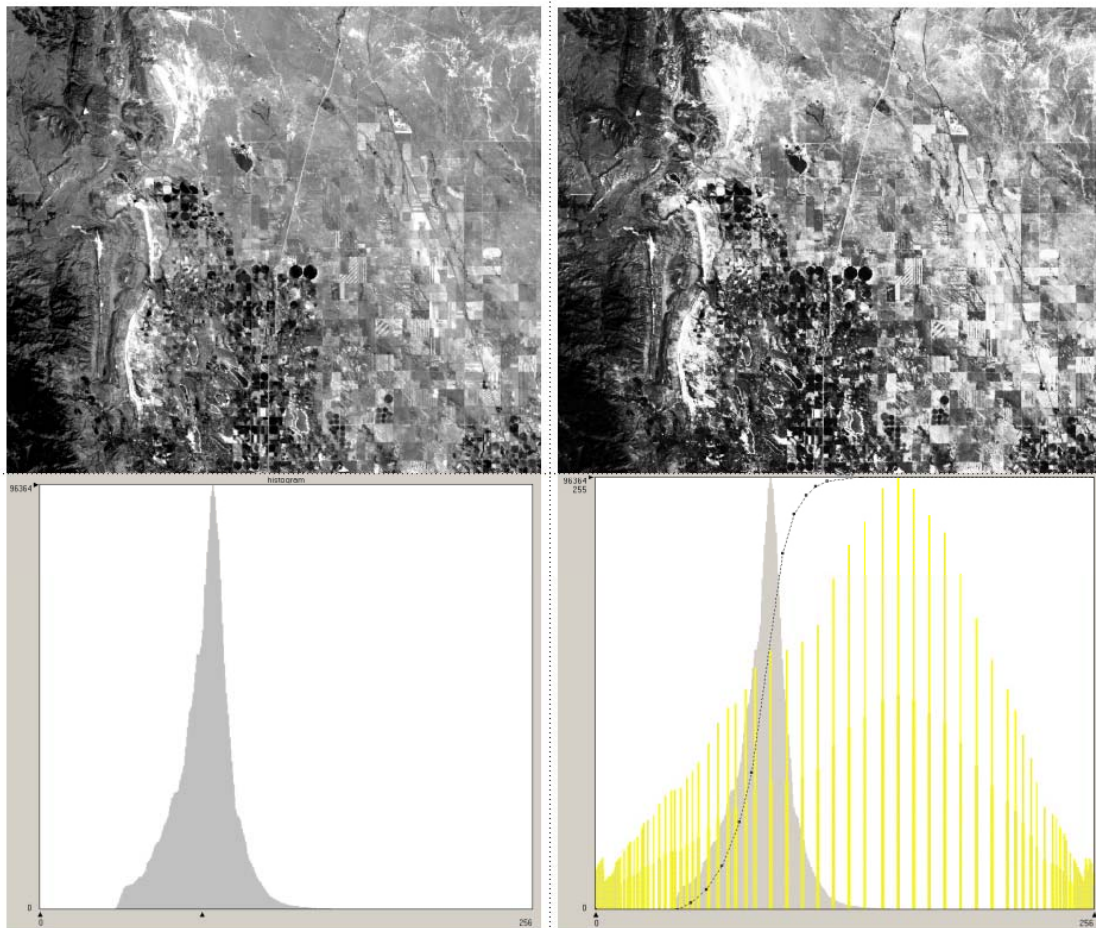
(6) *Logarithmic Enhancement*. Another type of enhancement stretch uses a logarithmic algorithm. This type of enhancement distinguishes lower DN values. The high intensity values are grouped together, which sacrifices the distinction of pixels with higher DN.

(7) *Manual Enhancement*. Some software packages will allow users to define an arbitrary enhancement. This can be done graphically or numerically. Manually adjusting the enhancement allows the user to reduce the signal noise in addition to reducing the contrast in unimportant pixels. **Note:** The processes described above do not alter the spectral radiance of the pixel raw data. Instead, the output display of the radiance is modified by a computed algorithm to improve image quality.

#### *b. Image Enhancement #2: Band Arithmetic*

(1) *Band Arithmetic*. Spectral band data values can be combined using arithmetic to create a new “band.” The digital number values can be summed, subtracted, multiplied, and divided (see equations 5-1 and 5-2). Image software easily performs these operations. This section will review only those arithmetic processes that involve the division or ratio of digital band data.

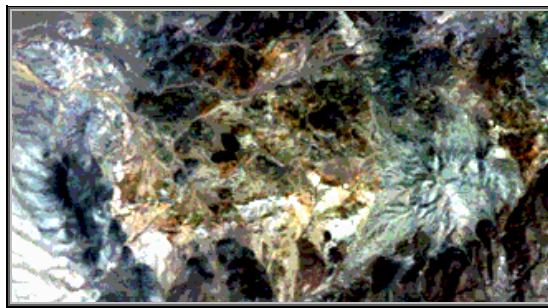
(2) *Band Ratio*. Band ratio is a commonly used band arithmetic method in which one spectral band is proportioned with another spectral band. This simple method reduces the effects of shadowing caused by topography, highlights particular image elements, and accentuates temporal differences (Figure 5-11).



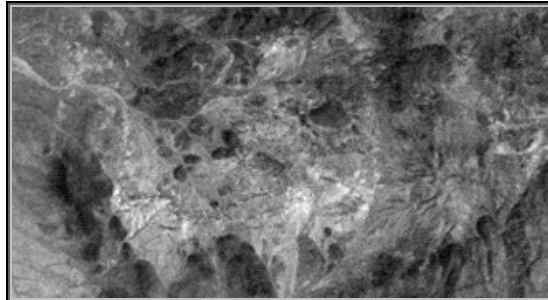
a. Image and its corresponding DN histogram show that the majority of pixels are clustered together (centering approximately on DN value of 100).

b. After histogram equalization stretch the pixels are reassigned new values and spread out across the entire value range. The data maximum is subdued while the histogram leading and trailing edges are amplified, the resulting image has an overall increase in contrast.

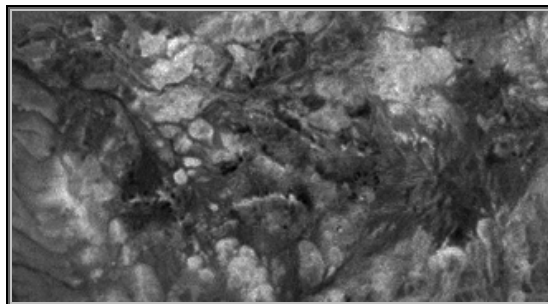
Figure 5-10. Landsat image of Denver area.



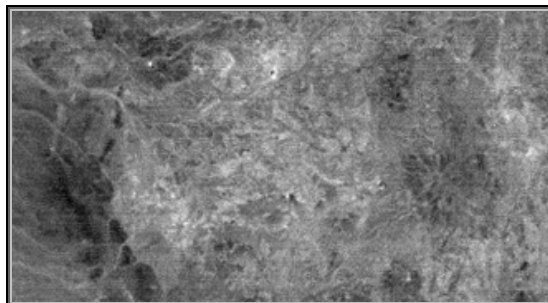
Landsat bands 3, 2, 1



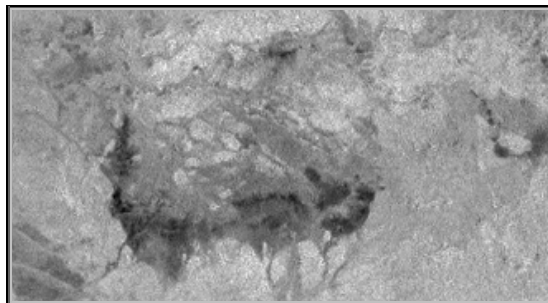
Band ratio 3/1 highlights hematite



Band ratio 1/7 highlights aluminum ore



Band ratio 7/5 highlights clays



Band ratio 4/2 highlights biomass

**Figure 5-11. NASA Landsat images from top to bottom: Color composite bands 3, 2, 1, band ratio 3/1 highlights iron oxide minerals, band ratios 7/5 and 1/7 reveals the presence of water in minerals—appropriate for mapping clay minerals or aluminum ore, and band ratio 4/2 allows for biomass determination.**

(3) *Shadow Removal from Data.* The effect of shadowing is typically caused by a combination of sun angle and large topographic features (i.e., shadows of mountains). Table 5-1 lists the pixel digital number values for radiance measured from two different objects for two bands (arbitrarily chosen) under differing lighting conditions. Pixel data representing the radiance reflecting off deciduous trees (trees that lose their leaves annually) is consistently higher for non-shadowed objects. This holds true as shadowing effectively lowers the pixel radiance. When the ratio of the two bands is taken (or divided by one another) the resultant ratio value is not influenced by the effects of shadowing (see Table 5-1). The band ratio therefore creates a more reliable data set.

**Table 5-1**  
**Effects of shadowing**

Tree type	Light conditions	Band A (DN)	Band B (DN)	Band A/B (ratio) (DN)
Deciduous Trees	In sunlight	48	50	0.96
	In shadow	18	19	0.95
Coniferous Trees	In sunlight	31	45	0.69
	In shadow	11	16	0.69

(4) *Emphasize Image Elements.* A number of ratios have been empirically developed and can highlight many aspects of a scene. Listed below are only a few common band ratios and their uses. When choosing bands for this method, it is best to consider bands that are poorly correlated. A greater amount of information can be extracted from ratios with bands that are covariant.

- B3/B1 – iron oxide
- B3/B4 – vegetation
- B4/B2 – vegetation biomass
- B4/B3 – known as the RVI (Ratio Vegetation Index)
- B5/B2 – separates land from water
- B7/B5 – hydrous minerals
- B1/B7 – aluminum hydroxides
- B5/B3 – clay minerals

(5) *Temporal Differences.* Band ratio can also be used to detect temporal changes in a scene. For instance, if a project requires the monitoring of vegetation change in a scene, a ratio of band 3 from image data collected at different times can be used. The newly created band file may have a name such as “Band3’Oct.98/Ban3’Oct.02.” When the new band is loaded, the resulting ratio will highlight areas of change; these pixels will appear brighter. For areas with no change, the resulting pixel values will be low and the resulting pixel will appear gray.

(a) One advantage of the ratio function lies in its ability to not only filter out the effects of shadowing but also the effects attributable to differences in sun angle. The sun angle may change from image to image for a particular scene. The sun angle is controlled by the time of day the data were collected as well as the time of year (seasonal effects). Processing images collected under different sun angle conditions may be un-

avoidable. Again, a ratio of the bands of interest will limit shadowing and sun angle effects. It is therefore possible to perform a temporal analysis on data collected at different times of the day or even at different seasons.

(b) A disadvantage of using band ratio is the emphasis that is placed on noise in the image. This can be reduced, however, by applying a spatial filter before employing the ratio function; this will reduce the signal noise. See Paragraph 5-20c.

(6) *Create a New Band with the Ratio Data.* Most software permits the user to perform a band ratio function. The band ratio function converts the ratio value to a meaningful digital number (using the 256 levels of brightness for 8-bit data). The ratio can then be saved as a new band and loaded onto a gray scale image or as a single band in a color composite.

(7) *Other Types of Ratios and Band Arithmetic.* There are a handful of ratios that highlight vegetation in a scene. The NDVI (Normalized Difference Vegetation Index; equations 5-1 and 5-2) is known as the “vegetation index”; its values range from -1 to 1.

$$\text{NDVI} = \frac{\text{NIR} - \text{red}}{\text{NIR} + \text{red}} \quad (5-1)$$

where NDVI is the normalized difference vegetation index, NIR is the near infrared, and red is the band of wavelengths coinciding with the red region of the visible portion of the spectrum. For Landsat TM data this equation is equivalent to:

$$\text{NDVI} = \frac{\text{Band 4} - \text{Band 3}}{\text{Band 4} + \text{Band 3}} \quad (5-2)$$

In addition to the NDVI, there is also IPVI (Infrared Percentage Vegetation Index), DVI (Difference Vegetation Index), and PVI (Perpendicular Vegetation Index) just to name a few. Variation in vegetation indices stem from the need for faster computations and the isolation of particular features. Figure 5-12 illustrates the NDVI.



**Figure 5-12. Top: True color CAMIS image. Bottom: NDVI mask isolating vegetated pixels. This mask will be useful during the classification process, which will subsequently classify only the vegetation in the scene while disregarding water and urban features. Taken from Campbell (2003).**

c. *Image Enhancement #3: Spatial Filters.* It is occasionally advantageous to reduce the detail or exaggerate particular features in an image. This can be done by a convolution method creating an altered or “filtered” output image data file. Numerous spatial filters have been developed and can be automated within software programs. A user can also develop his or her own spatial filter to control the output data set. Presented below is a short introduction to the method of convolution and a few commonly used spatial filters.

(1) *Spatial Frequency.* Spatial frequency describes the pattern of digital values observed across an image. Images with little contrast (very bright or very dark) have zero spatial frequency. Images with a gradational change from bright to dark pixel values have low spatial frequency; while those with large contrast (black and white) are said to have high spatial frequency. Images can be altered from a high to low spatial frequency with the use of convolution methods.

(2) *Convolution.*

(a) Convolution is a mathematical operation used to change the spatial frequency of digital data in the image. It is used to suppress noise in the data or to exaggerate features of interest. The operation is performed with the use of a spatial kernel. A kernel is an array of digital number values that form a matrix with odd numbered rows and columns (Table 5-2). The kernel values, or coefficients, are used to average each pixel relative to its neighbor across the image. The output data set will represent the averaging effect of the kernel coefficients. As a spatial filter, convolution can smooth or blur images, thereby reducing image noise. In feature detection, such as an edge enhancement, convolution works to exaggerate the spatial frequency in the image. Kernels can be reapplied to an image to further smooth or exaggerate spatial frequency.

(b) Low pass filters apply a small gain to the input data (Table 5-2a). The resulting output data will decrease the spatial frequency by de-emphasizing relatively bright pixels. Two types of low pass filters are the simple mean and center-weighted mean methods (Table 5-2a and b). The resultant image will appear blurred. Alternatively, high pass frequency filters (Table 5-2c) increase image spatial frequency. These types of filters exaggerate edges without reducing image details (an advantage over the Laplacian filter discussed below).

(2) *Laplacian or Edge Detection Filter.*

(a) The Laplacian filter detects discrete changes in spectral frequency and is used for highlighting edge features in images. This type of filter works well for delineating linear features, such as geologic strata or urban structures. The Laplacian is calculated by an edge enhancement kernel (Table 5-2d and e); the middle number in the matrix is much higher or lower than the adjacent coefficients. This type of kernel is sensitive to noise and the resulting output data will exaggerate the pixel noise. A smoothing convolution filter can be applied to the image in advance to reduce the edge filter's sensitivity to data noise.

## The Convolution Method

Convolution is carried out by overlaying a kernel onto the pixel image and centering its middle value over the pixel of interest. The kernel is first placed above the pixel located at the top left corner of the image and moved from top to bottom, left to right. Each kernel position will create an output pixel value, which is calculated by multiplying each input pixel value with the kernel coefficient above it. The product of the input data and kernel is then averaged over the array (sum of the product divided by the number of pixels evaluated); the output value is assigned this average. The kernel then moves to the next pixel, always using the original input data set for calculating averages. Go to <http://www.cla.sc.edu/geog/rslab/Rsc/rsc-frames.html> for an in-depth description and examples of the convolution method.

The pixels at the edges create a problem owing to the absence of neighboring pixels. This problem can be solved by inventing input data values. A simpler solution for this problem is to clip the bottom row and right column of pixels at the margin.

(b) The Laplacian filter measures the changes in spectral frequency or pixel intensity. In areas of the image where the pixel intensity is constant, the filter assigns a digital number value of 0. Where there are changes in intensity, the filter assigns a positive or negative value to designate an increase or decrease in the intensity change. The resulting image will appear black and white, with white pixels defining the areas of changes in intensity.

**Table 5-2**

**Variety in 9-Matrix Kernel Filters Used in a Convolution Enhancement.** Each graphic shows a kernel, an example of raw DN data array, and the resultant enhanced data array. See <http://www.cee.hw.ac.uk/hipr/html/filtops.html> for further information on kernels and the filtering methods.

### a. Low Pass: simple mean kernel.

1	1	1
1	1	1
1	1	1

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	10	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Raw data

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	2	2	2	1	1
1	1	2	2	2	1	1
1	1	2	2	2	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Output data

**b. Low Pass: center weighted mean kernel.**

1	1	1
1	2	1
1	1	1

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	10	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Raw data

1	1	1	1	1	1	1
1	1	1	1	1	1	1
1	1	2	2	2	1	1
1	1	2	3	2	1	1
1	1	2	2	2	1	1
1	1	1	1	1	1	1
1	1	1	1	1	1	1

Output data

**c. High Pass kernel.**

-1	-1	-1
-1	8	-1
-1	-1	-1

10	10	10	10	10	10	10
10	10	10	10	10	10	10
10	10	10	10	10	10	10
10	10	10	15	10	10	10
10	10	10	10	10	10	10
10	10	10	10	10	10	10
10	10	10	10	10	10	10

Raw data

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	-5	-5	-5	0	0
0	0	-5	40	-5	0	0
0	0	-5	-5	-5	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Output data

**d. Direction Filter: north-south component kernel.**

-1	2	-1
-2	1	-2
-1	2	-1

1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1

Raw data

0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0
0	0	-4	8	-4	0	0

Output data

**e. Direction Filter: East-west component kernel.**

-1	-2	-1
2	4	2
-1	-2	-1

1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1
1	1	1	2	1	1	1

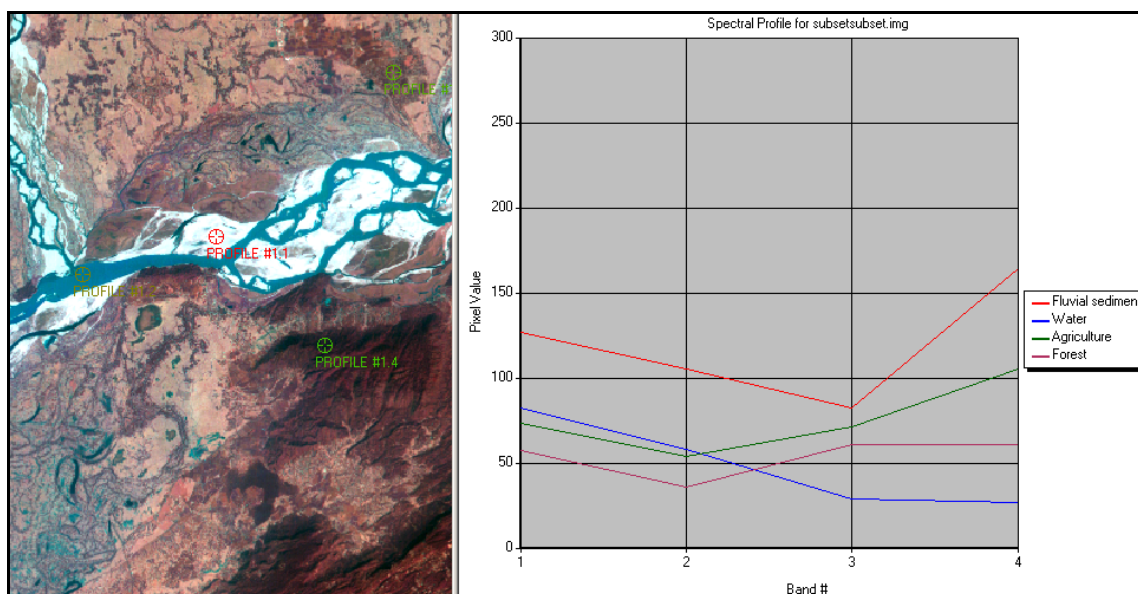
Raw data

0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Output data

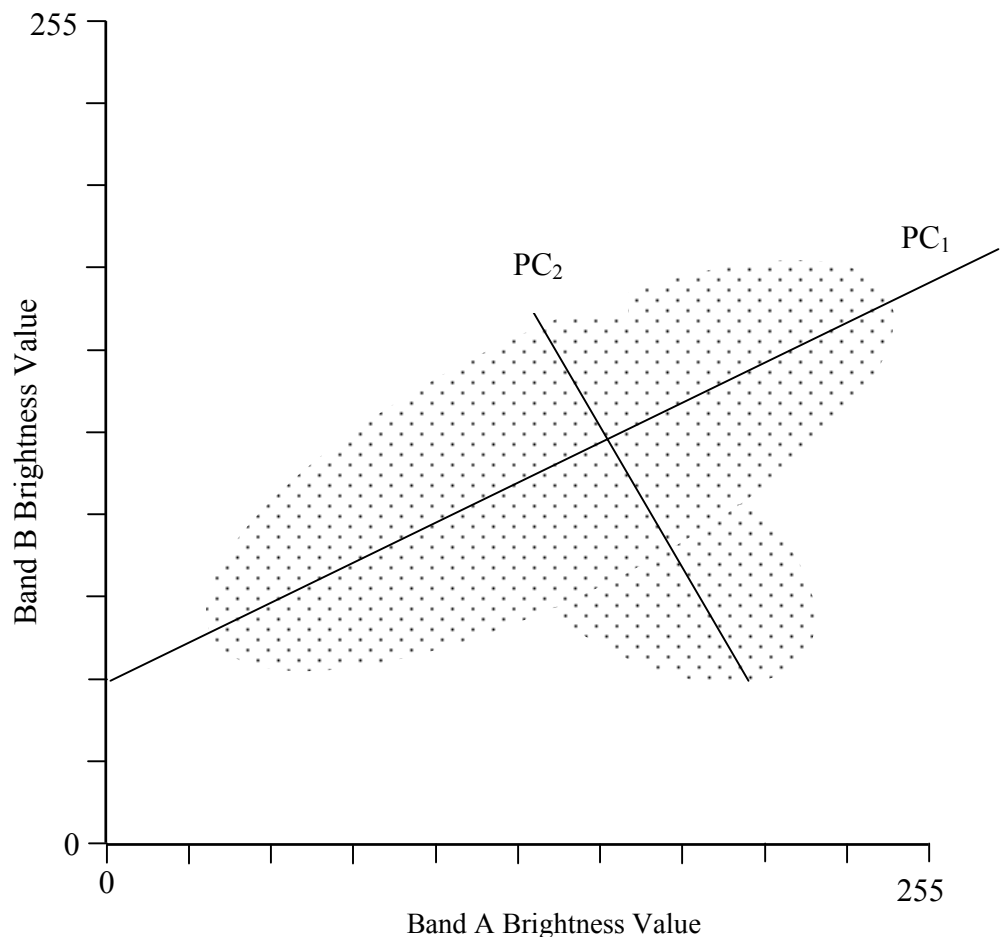
d. *Image Enhancement #4: Principle Components.* The principle component analysis (PCA) is a technique that transforms the pixel brightness values. This transformation compresses the data by drawing out maximum covariance and removes correlated elements. The resulting data will contain new, uncorrelated data that can be later used in classification techniques.

(1) *Band Correlation.* Spectral bands display a range of correlation from one band to another. This correlation is easily viewed by bringing up a scatter plot of the digital data and plotting, for instance, band 1 vs. band 2. Many bands share elements of information, particularly bands that are spectrally close to one another, such as band 1 and 2. For bands that are highly correlated, it is possible to predict the brightness outcome of one band with the data of the other (Figure 5-13). Therefore, bands that are well correlated may not be of use when attempting to isolate spectrally similar objects.



**Figure 5-13. Indian IRS-1D image and accompanying spectral plot. Representative pixel points for four image elements (fluvial sediment in a braided channel, water, agriculture, and forest) are plotted for each band. Plot illustrates the ease by which each element can be spectrally separated. For example, water is easily distinguishable from the other elements in band 2.**

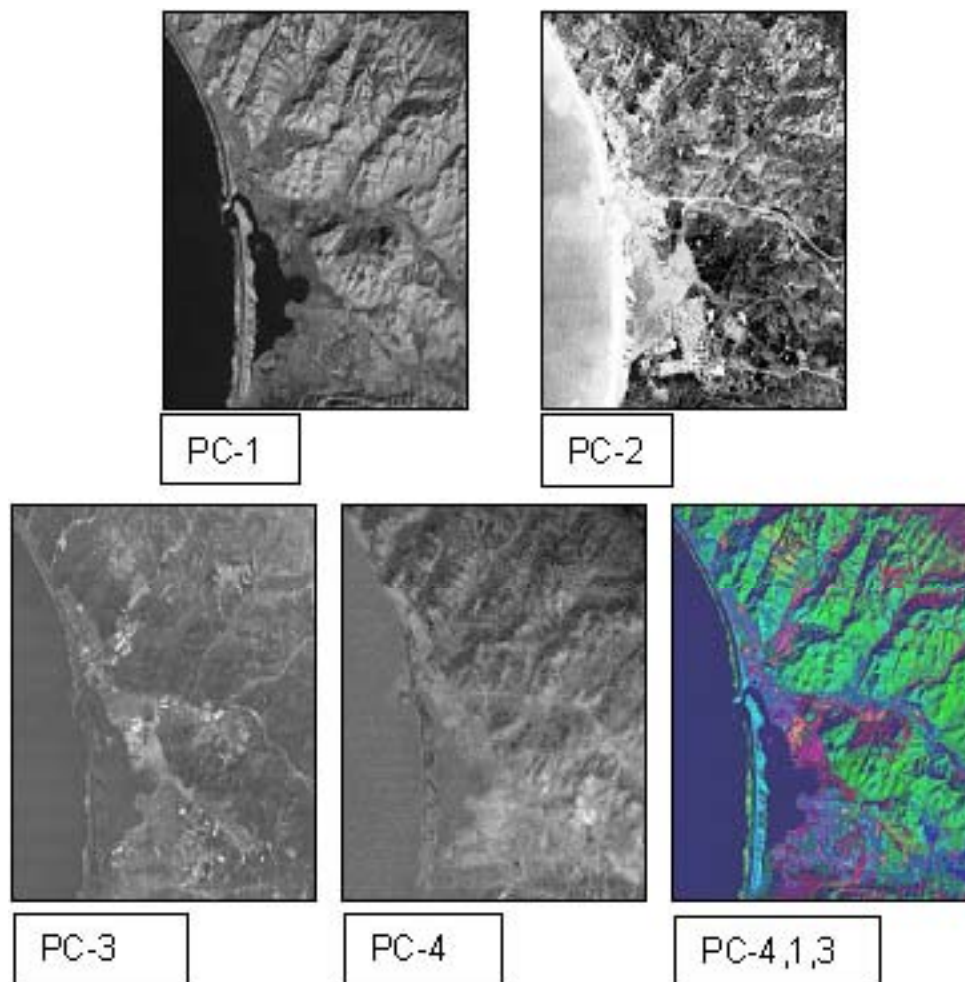
(2) *Principle Component Transformation.* The principle component method extracts the small amount of variance that may exist between two highly correlated bands and effectively removes redundancy in the data. This is done by “transforming” the major vertical and horizontal axes. The transformation is accomplished by rotating the horizontal axis so that it is parallel to a least squares regression line that estimates the data. This transformed axis is known as  $PC_1$ , or Principle Component 1. A second axis,  $PC_2$ , is drawn perpendicular to  $PC_1$ , and its origin is placed at the center of the  $PC_1$  range (Figure 5-14). The digital number values are then re-plotted on the newly transformed axes. This transformation will result in data with a broader range of values. The data can be saved as a separate file and loaded as an image for analysis.



**Figure 5-14.** Plot illustrates the spectral variance between two bands, A and B.  $PC_1$  is the line that captures the mean of the data set.  $PC_2$  is orthogonal to  $PC_1$ .  $PC_1$  and  $PC_2$  become the new horizontal and vertical axis; brightness values are redrawn onto the  $PC_1$  and  $PC_2$  scale.

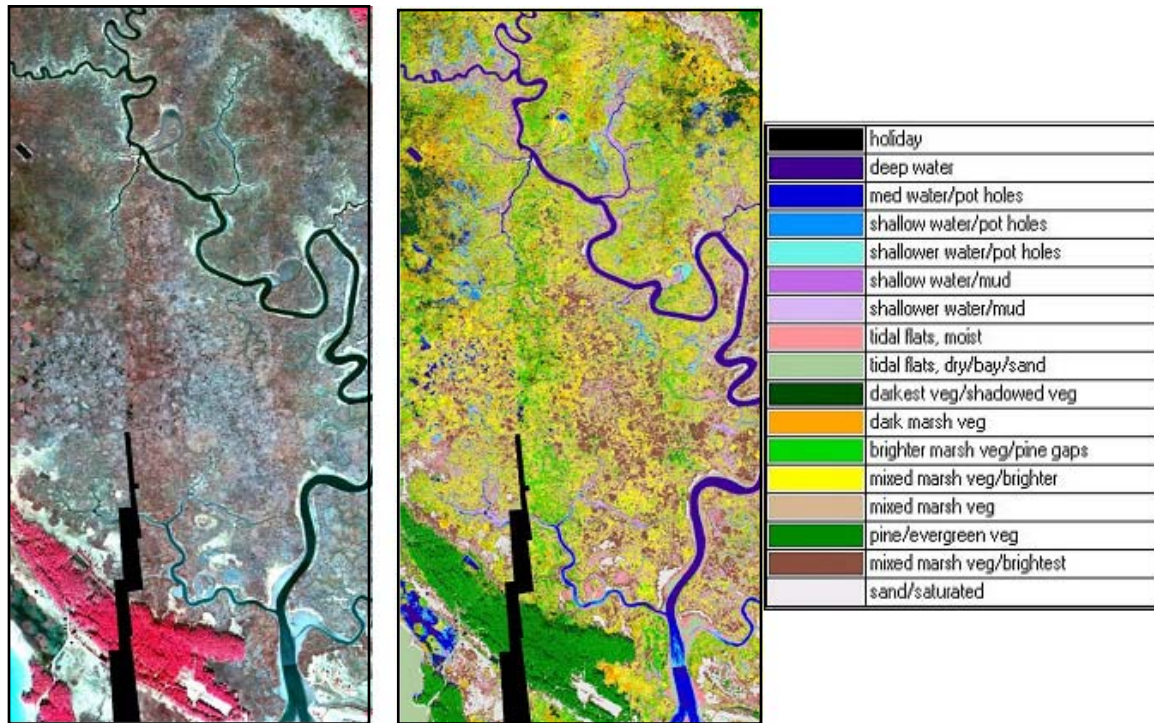
*c. Transformation Series ( $PC_1$ ,  $PC_2$ ,  $PC_3$ ,  $PC_4$ ,  $PC_5$ , etc.).* The process of transforming the axis to fit the maximum variance in the data can be performed in succession on the same data set. Each successive axis rotation creates a new principal component axis; a series of transformations can then be saved as individual files. Band correlation is greatly reduced in the first PC transformation, 90% of the variance between the bands will be isolated by  $PC_1$ . Each principle component transformation extracts less and less variance,  $PC_2$ , for instance, isolates 5% of the variance, and  $PC_3$  will extract 3% of the variance, and so on (Figure 5-15). Once  $PC_1$  and  $PC_2$  have been processed, approximately 95% of the variance within the bands will be extracted. In many cases, it is not useful to extract the variance beyond the third principle component. Because the principle component function reduces the size of the original data file, it functions as a pre-processing tool and better prepares the data for image classification. The de-correlation of band data in the principle component analysis is mathematically complex. It linearly

transforms the data using a form of factor analysis (eigen value and eigen vector matrix). For a complete discussion of the technique see Jensen (1996).



**Figure 5-15. PC-1 contains most of the variance in the data. Each successive PC-transformation isolates less and less variation in the data. Taken from <http://rst.gsfc.nasa.gov/start.html>.**

*d. Image Classification.* Raw digital data can be sorted and categorized into thematic maps. Thematic maps allow the analyst to simplify the image view by assigning pixels into classes with similar spectral values (Figure 5-16). The process of categorizing pixels into broader groups is known as image classification. The advantage of classification is it allows for cost-effective mapping of the spatial distribution of similar objects (i.e., tree types in forest scenes); a subsequent statistical analysis can then follow. Thematic maps are developed by two types of classifications, supervised and unsupervised. Both types of classification rely on two primary methods, training and classifying. Training is the designation of representative pixels that define the spectral signature of the object class. Training site or training class is the term given to a group of training pixels. Classifying procedures use the training class to classify the remaining pixels in the image.



**Figure 5-16. Landsat image (left) and its corresponding thematic map (right) with 17 thematic classes. The black zigzag at bottom of image is the result of shortened flight line over-lap. (Campbell, 2003).**

(1) *Supervised Classification.* Supervised classification requires some knowledge about the scene, such as specific vegetative species. Ground truth (field data), or data from aerial photographs or maps can all be used to identify objects in the scene.

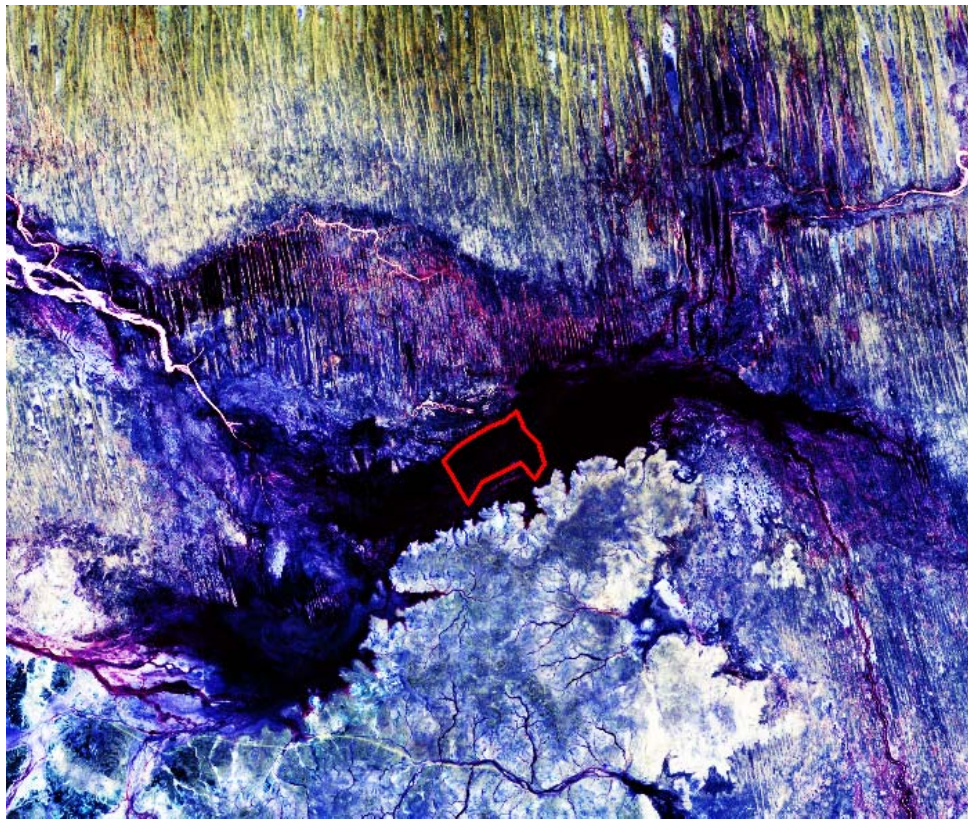
(2) *Steps Required for Supervised Classification.*

(a) Firstly, acquire satellite data and accompanying metadata. Look for information regarding platform, projection, resolution, coverage, and, importantly, meteorological conditions before and during data acquisition.

(b) Secondly, chose the surface types to be mapped. Collect ground truth data with positional accuracy (GPS). These data are used to develop the training classes for the discriminant analysis. Ideally, it is best to time the ground truth data collection to coincide with the satellite passing overhead.

(c) Thirdly, begin the classification by performing image post-processing techniques (corrections, image mosaics, and enhancements). Select pixels in the image that are representative (and homogeneous) of the object. If GPS field data were collected, geo-register the GPS field plots onto the imagery and define the image training sites by outlining the GPS polygons. A training class contains the sum of points (pixels) or polygons (clusters of pixels) (see Figures 5-17 and 5-18). View the spectral histogram to inspect the homogeneity of the training classes for each spectral band. Assign a color to represent each class and save the training site as a separate file. Lastly, extract the re-

maining image pixels into the designated classes by using a discriminate analysis routine (discussed below).



**Figure 5-17. Landsat 7 ETM image of central Australia (4, 3, 2 RGB). Linear features in the upper portion of the scene are sand dunes. Training data are selected with a selection tool (note the red enclosure). A similar process was performed on data from Figure 5-16 (the DN values for figure 5-16 are presented in Figure 5-18).**

SORT #	CLASS NAME	COLOR	TRAINING	CLASSIFIED	% TOTAL	% DATA
1	Unclassified			25,207,732	68.86%	
2	ROAD	Red1	77	0	0.00%	0.00
3	AG	Green1	1642	0	0.00%	0.00
4	LP	Red1	4148	2,164,089	5.91%	19.53
5	LPO	Blue1	5627	1,562,180	4.27%	14.10
6	LPH	Maroon1	4495	2,170,395	5.93%	19.58
7	MHW-low	Aquamarine	888	329,360	0.90%	2.97
8	CUT	Chartreuse	1219	1,055,063	2.88%	9.52
9	MHW-high	Sienna1	3952	1,566,698	4.28%	14.14
10	MORT	Green3	1703	4,651	0.01%	0.04
12	juncus-low-density	Red1	52	37,808	0.10%	0.34
13	juncus-high-density	Blue1	65	102,174	0.28%	0.92
13	juncus-panicum-mix	Cyan1	53	0	0.00%	0.00
14	juncus-mixed-clumps-field	Magenta1	29	3	0.00%	0.00
16	g1=hd-scol+background+w	Green1	32	610,283	1.67%	5.51
17	g2=md-scol+background	Yellow1	29	952	0.00%	0.01
18	g4=md-scol+spartina+mud	Maroon1	36	0	0.00%	0.00
19	g3=md-scol+spartina+background	Purple1	50	0	0.00%	0.00
20	g5=ld-scol+mud	Aquamarine	56	617	0.00%	0.01
21	g1=md-spal+w	Red1	66	4,789	0.01%	0.04
22	g2=hd-spal+w	Green1	52	141,060	0.39%	1.27
23	g3=hd-spal+w+sppa	Cyan1	29	803,145	2.19%	7.25
24	g4=md-spal+w+sppa	Magenta1	44	0	0.00%	0.00
25	g5=hd-spal+mud	Red1	25	25	0.00%	0.00
26	g6=mixed-spal	Chartreuse	28	6,555	0.02%	0.06
26	g7=md-spal+lit+mud	Thistle1	36	6	0.00%	0.00
28	g8=md-mixed-spal	Blue4	85	0	0.00%	0.00
29	g1=hd-sppa+mix	Red1	37	74	0.00%	0.00
30	g2=hd-sppa+mud	Blue1	40	0	0.00%	0.00
31	g3=mhd-sppa+spal+background	Cyan1	32	939	0.00%	0.01
32	g4=lmd-sppa+mix+background	Magenta1	160	0	0.00%	0.00
33	g9=ld-sppa+spal+mud	Blue4	28	520,290	1.42%	4.69
34	g10=ld-sppa+mix+background	Cyan3	45	0	0.00%	0.00
35	g11=ld-sppa+w+mix	Green2	32	1,255	0.00%	0.01
37				11082411.00		

**Figure 5-18. Classification training data of 35 landscape classification features.** “Training” provides the pixel count after training selection; classification provides the image pixel count after a classification algorithm is performed. This data set accompanies Figure 5-16, the classified image. (Campbell, 2003).

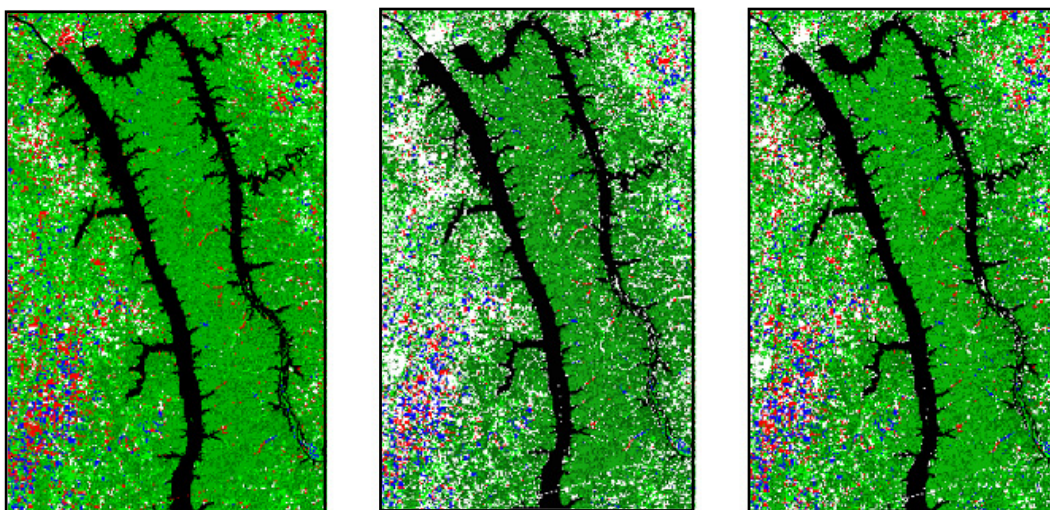
(3) *Classification Algorithms.* Image pixels are extracted into the designated classes by a computed discriminant analysis. The three types of discriminant analysis algorithms are: minimum mean distance, maximum likelihood, and parallelepiped. All use brightness plots to establish the relationship between individual pixels and the training class (or training site).

(a) *Minimum Mean Distance.* Minimum distance to the mean is a simple computation that classifies pixels based on their distance from the mean of the training class.

It is determined by plotting the pixel brightness and calculating its Euclidean distance (using the Pythagorean theorem) to the unassigned pixel. Pixels are assigned to the training class for which it has a minimum distance. The user designates a minimum distance threshold for an acceptable distance; pixels with distance values above the designated threshold will be classified as unknown.

(b) *Parallelepiped*. In a parallelepiped computation, unassigned pixels are grouped into a class when their brightness values fall within a range of the training mean. An acceptable digital number range is established by setting the maximum and minimum class range to plus and minus the standard deviation from the training mean. The pixel brightness value simply needs to fall within the class range, and is not based on its Euclidean distance. It is possible for a pixel to have a brightness value close to a class and not fall within its acceptable range. Likewise, a pixel may be far from a class mean, but fall within the range and therefore be grouped with that class. This type of classification can create training site overlap, causing some pixels to be misclassified.

(c) *Maximum Likelihood*. Maximum Likelihood is computationally complex. It establishes the variance and covariance about the mean of the training classes. This algorithm then statistically calculates the probability of an unassigned pixel belonging to each class. The pixel is then assigned to the class for which it has the highest probability. Figure 5-19 visually illustrates the differences between these supervised classification methods.



**Figure 5-19.** From left to right, minimum mean distance, parallelepiped, and maximum likelihood. Courtesy of the Department of Geosciences at Murray State University.

(4) *Assessing Error*. Accuracy can be qualitatively determined by an error matrix (Table 5-3). The matrix establishes the level of errors due to omission (exclusion error), commission (inclusion error), and can tabulate an overall total accuracy. The error matrix lists the number of pixels found within a given class. The rows in Table 5-2 list the pixels classified by the image software. The columns list the number of pixels in the reference data (or reported from field data). Omission error calculates the probability of

a pixel being accurately classified; it is a comparison to a reference. Commission determines the probability that a pixel represents the class for which it has been assigned. The total accuracy is measured by calculating the proportion correctly classified pixel relative to the total tested number of pixels (Total = total correct/total tested).

**Table 5-3**  
**Omission and Commission Accuracy Assessment Matrix. Taken from Jensen (1996).**

Reference Data						
Classification	Residential	Commercial	Wetland	Forest	Water	Raw Total
Residential	70	5	0	13	0	88
Commercial	3	55	0	0	0	58
Wetland	0	0	99	0	0	99
Forest	0	0	4	37	0	41
Water	0	0	0	0	121	121
Column Total	73	60	103	50	121	407
Overall Accuracy = 382/407=93.86%						

Producer's Accuracy (measure of omission error)

Residential=  $70/73 = 96-4\%$  omission error  
Commercial=  $55/60 = 92-8\%$  omission error  
Wetland=  $99/103 = 96-4\%$  omission error  
Forest=  $37/50 = 74-26\%$  omission error  
Water=  $121/121 = 100-0\%$  omission error

User's Accuracy (measure of commission error)

Residential=  $70/88 = 80-20\%$  omission error  
Commercial=  $55/58 = 95-5\%$  omission error  
Wetland=  $99/99 = 100-0\%$  omission error  
Forest=  $37/41 = 90-10\%$  omission error  
Water=  $121/121 = 100-0\%$  omission error

Example error matrix taken from Jensen (1986). Data are the result of an accuracy assessment of Landsat TM data.

### Classification method summary

Image classification uses the brightness values in one or more spectral bands, and classifies each pixel based on its spectral information

The goal in classification is to assign remaining pixels in the image to a designated class such as water, forest, agriculture, urban, etc.

The resulting **classified** image is composed of a collection of pixels, color-coded to represent a particular theme. The overall process then leads to the creation of a thematic map to be used to visually and statistically assess the scene.

(5) *Unsupervised Classification.* Unsupervised classification does not require prior knowledge. This type of classification relies on a computed algorithm that clusters pixels based on their inherent spectral similarities.

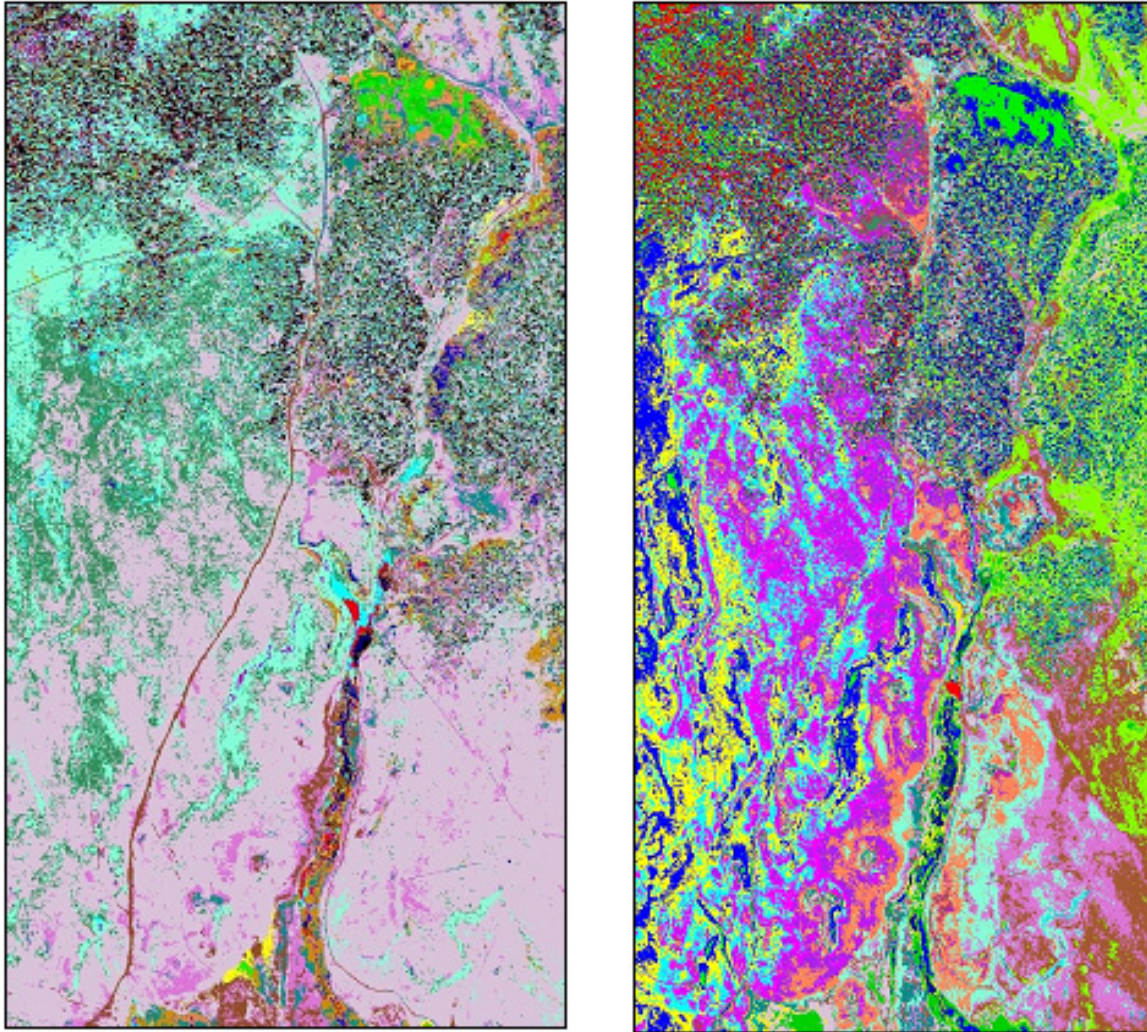
(a) *Steps Required for Unsupervised Classification.* The user designates 1) the number of classes, 2) the maximum number of iterations, 3) the maximum number of times a pixel can be moved from one cluster to another with each iteration, 4) the minimum distance from the mean, and 5) the maximum standard deviation allowable. The program will iterate and recalculate the cluster data until it reaches the iteration threshold designated by the user. Each cluster is chosen by the algorithm and will be evenly distributed across the spectral range maintained by the pixels in the scene. The resulting classification image (Figure 5-20) will approximate that which would be produced with the use of a minimum mean distance classifier (see above, “classification algorithm”). When the iteration threshold has been reached the program may require you to rename and save the data clusters as a new file. The display will automatically assign a color to each class; it is possible to alter the color assignments to match an existing color scheme (i.e., blue = water, green = vegetation, red = urban) after the file has been saved. In the unsupervised classification process, one class of pixels may be mixed and assigned the color black. These pixels represent values that did not meet the requirements set by the user. This may be attributable to spectral “mixing” represented by the pixel.

(b) *Advantages of Using Unsupervised Classification.* Unsupervised classification is useful for evaluating areas where you have little or no knowledge of the site. It can be used as an initial tool to assess the scene prior to a supervised classification. Unlike supervised classification, which requires the user to hand select the training sites, the unsupervised classification is unbiased in its geographical assessment of pixels.

(c) *Disadvantages of Using Unsupervised Classification.* The lack of information about a scene can make the necessary algorithm decisions difficult. For instance, without knowledge of a scene, a user may have to experiment with the number of spectral clusters to assign. Each iteration is time consuming and the final image may be difficult to interpret (particularly if there is a large number of unidentified pixels such as those in Figure 5-19). The unsupervised classification is not sensitive to covariation and variations in the spectral signature to objects. The algorithm may mistakenly separate pixels with slightly different spectral values and assign them to a unique cluster when they, in fact, represent a spectral continuum of a group of similar objects.

(6) *Evaluating Pixel Classes.* The advantages of both the supervised and unsupervised classification lie in the ease with which programs can perform statistical analysis. Once pixel classes have been assigned, it is possible to list the exact number of pixels in each representative class (Figure 5-17, classified column). As the size of each pixel is known from the metadata, the metric area of each class can be quickly calculated. For example, you can very quickly deter-

mine the percentage of fallow field area versus productive field area in an agricultural scene.



**Figure 5-20. Unsupervised and supervised classification of a clay-mine (upper center, bright green pixels) imaged with HyMap hyperspectral data. Images courtesy of Dr. Brigitte Martini at the Earth Sciences Department, University of California, Santa Cruz, CA. Go to <http://www.es.ucsc.edu/~hyperwww/chevron/whatisrs5.html> for details on the image.**

*e. Image Mosaics, Image subsets, and Multiple Image Analysis.*

(1) *Image Mosaics.* It is not uncommon for a study area to include areas beyond the range of an individual scene. In such a case, it will be necessary to collect adjacent scenes and mosaic or piece them together (Figures 5-21–5-23). It is preferable to choose scenes with data collected during the same season or general time frame and under similar weather conditions. Images can only be properly pieced together if their data are registered in the same projection and datum. It will be important to assess the registration of all images before attaching the scenes together. If any of the images are misregistered, this will lead to gaps in the image or it will create pixel overlay.

(2) *Image Mosaic and Image Subset*. The mosaic process is a common feature in image processing programs. It is best to perform image enhancements prior to piecing separate scenes together. Once the images are pieced together, the resulting image may be large and include areas outside the study region. It is good practice to take a subset of this larger scene to reduce the size of the image file. This will make subsequent image processing faster. To do this, use the clip or subset function in a software program. The clip function will need to know the corner coordinates of the subset (usually the upper left and lower right). Some software may require this procedure to be repeated for each individual band of data. The subset should be named and saved as a separate file or files. **Note:** An image subset may also be required if the margins of a newly registered scene are skewed, or if the study only requires a small portion of one scene. Reduction of the spatial dimensions of a scene reduces the image file size, simplifies image classification, and prepares the image for map production.

**Example:** Calculate the percentage of land cover types for a classification performed on a Landsat TM image with a spatial resolution of 30 m using a supervised maximum likelihood classification with a 3.0 standard deviation.

**Solution:** Calculate the percentage based on the total

**Percent Calculation**

Class	Number of class pixels	Percentage
Water	16,903	$(16,903/413,469) \times 100 = 4.1\%$
Forest:	368,641	$(368,641/413,469) \times 100 = 89.1\%$
Wetlands	6,736	$(6,736/413,469) \times 100 = 1.6\%$
Agriculture	13,853	$(13,853/413,469) \times 100 = 3.4\%$
Urban	6,255	$(6,255/413,469) \times 100 = 1.5\%$
Unknown	1081	$(1081/413,469) \times 100 = 0.3\%$
Total	413,469	$(413,469/413,469) \times 100 = 100\%$

Maximum likelihood is a superior classifier and training classes are well defined. This is evident in the low number of pixels in the unknown class.

Area can be calculated using the number of pixels in a class and multiplying it by the ground dimensions of the pixel. For example the number of square meters and hectares in the wetland class of this example is:

Wetlands	$6,736 \times (30\text{m})^2 = 6.1 \times 10^6 \text{ m}^2$	606.24 ha
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This last step is often not necessary as many software programs automatically calculate the hectares for each class.

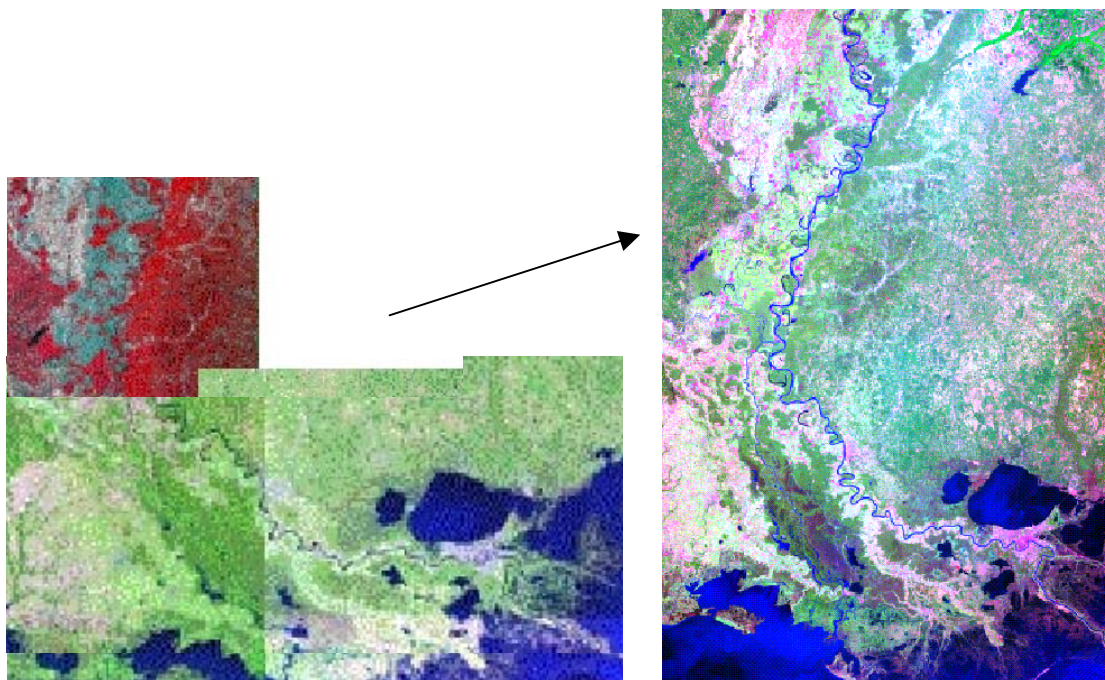


Figure 5-21. Multiple Landsat TM images, shown on the left (some sub-scenes are not shown here) were pieced together to create the larger mosaic image on the right. The seams within the mosaic image (right) are virtually invisible, an indication of the accuracy of the projection. Taken from Prospect (2002 and 2003).

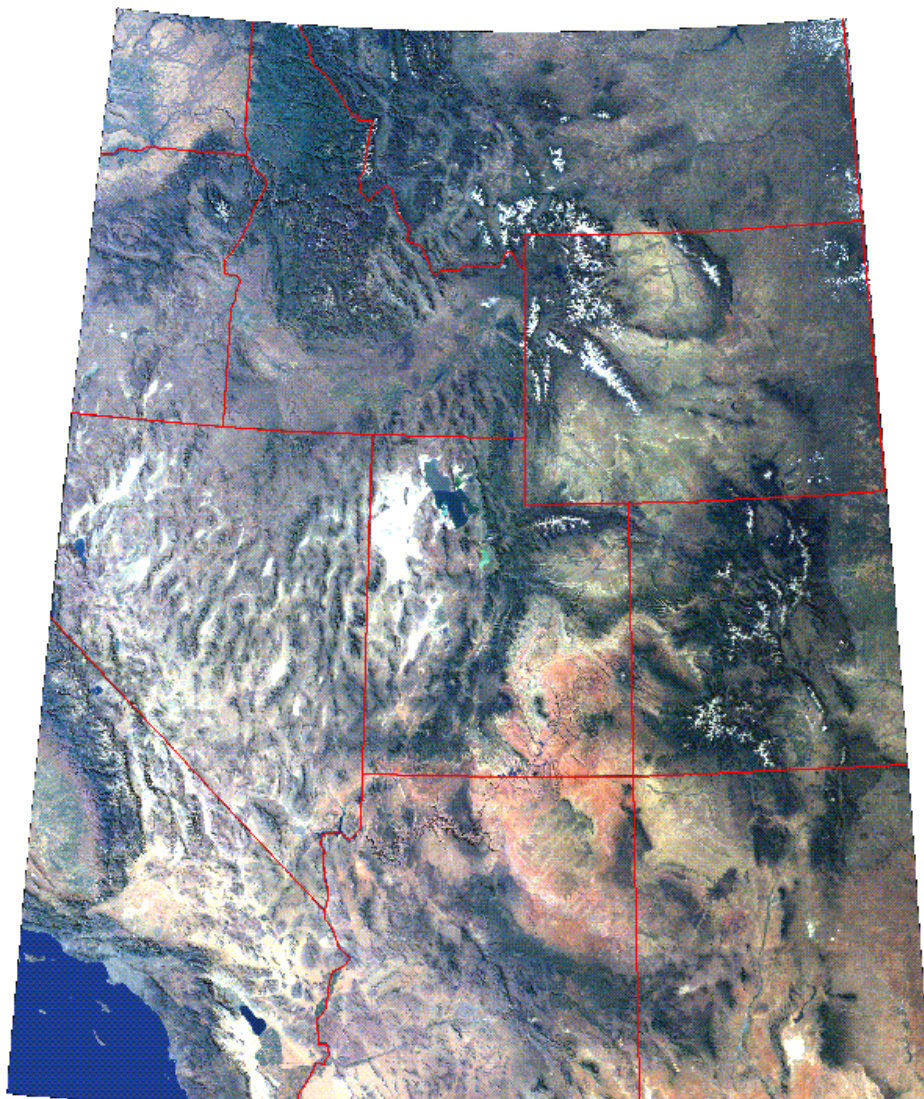
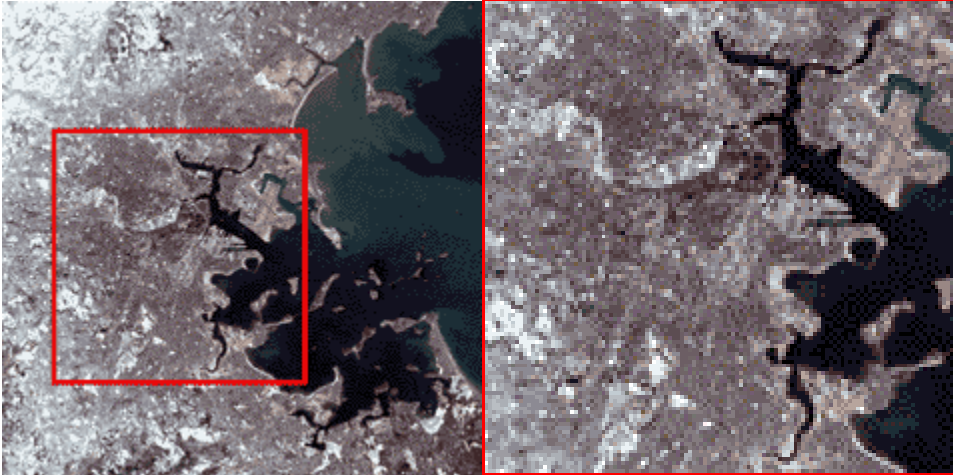


Figure 5-22. Multi-image mosaic of Western United States centered on the state of Utah. Mosaic seams are invisible in this scene, an indication of good radiometric and geometric corrections. The skewed and curved margins are an artifact of the rectification and mosaic process. Taken from [http://www.jpl.nasa.gov/images/earth/usa/misr\\_020602\\_2.html](http://www.jpl.nasa.gov/images/earth/usa/misr_020602_2.html).



**Figure 5-23. Landsat 7 Image of the Boston, Massachusetts area. Image on the right shows red box outlining the boundaries of the subset scene on the left. Taken from <http://landsat.gsfc.nasa.gov/education/l7downloads/index.html>.**

(3) *Multiple-image Temporal Analysis.* It is possible to combine bands from different images or data sets. This allows a user to perform a change detection analysis. The process of “layering” multi-temporal data involves loading a composite of bands from different images of the same scene. For example, a study assessing urban development in a forested area would benefit from examining a band combination that included band 3 data in the red plane, and band 3 data of a later image in the green plane. If the spectral signature of the scene has changed and is detectable within the resolution of the data, then changes in the scene will be highlighted. This image can then be classified and the areas of change can be statistically assessed. To perform this task accurately, it is important that both images are registered properly. Misregistration will lead to an offset in the image, which leaves brightly colored lines of pixels. Be sure to choose images whose data were collected under similar conditions, such as the same season, time of day, and prevailing weather, i.e., minimum cloud cover.

*f. Remote Sensing and Geospatial Information.* Remote sensing data are easily integrated with other digital data, such as vector data used in a GIS (Geographical Information System). Vector data can be incorporated into a raster satellite image by overlaying the data onto an image scene. Conversely, a raster image can be saved as a .jpeg or .tiff file and exported to a vector software processing program. Remote sensing data files can provide land cover and use information as well as digital elevation models (DEMs), and a number of geo-physical and biophysical parameters. Satellite images coupled with GIS data can be used to create original maps. The use of remote sensing in this type of application can drastically cut costs of GIS database development. It also provides data for inaccessible areas.

(1) *Digital Orthoquadrangle (DOQs).* A digital orthoquadrangle (DOQ) is a digital image of an aerial photograph that has had ground relief removed and is

geometrically corrected. The removal of ground relief adds to the accuracy measurement of distances on the ground. DOQs are available over the internet through the USGS or state level natural resources and environmental agencies. They come in black and white and color infrared. These digital aerial photographs come in a variety of scales and resolutions (often 1-m GSD). Due to the ortho-correction process, DOQs are typically in UTM, Geographic, or State Plane Projection. The images typically have 50 to 300 m overlap. This overlap simplifies the mosaic process. DOQs work well in combination with GIS data and may aid in the identification of objects in a satellite scene. It is possible to link a DOQ with a satellite image and a one-to-one comparison can be made between a pixel on the satellite image and the same geographic point on the DOQ.

(2) *Digital Elevation Models (DEM)*. A Digital Elevation Model (DEM) is a digital display of cartographic elements, particularly topographic features. DEMs utilize two primary types of data, DTM (digital terrain model) or DSM (digital surface model). The DTM represents elevation points of the ground, while DSM is the elevation of points at the surface, which includes the top of buildings and trees, in addition to terrain. The DEM incorporates the elevation data and projects it relative to a coordinate reference point. (See <http://www.ipf.tuwien.ac.at/fr/buildings/diss/node27.html> for more information on DEM, DTM, and DSMs.

(3) *DEM Generation*. Elevation measurements are sampled at regular intervals to form an array of elevation points within the DEM. The elevation data are then converted to brightness values and can be displayed as a gray scale image (Figure 5-24). The model can be viewed in image processing software and superimposed onto satellite image data. The resulting image will appear as a “three-dimensional” view of the image data.

(a) DEMs come in a variety of scales and resolutions. Be sure to check the date and accuracy of the DEM file. DEMs produced before 2001 have as much as 30 m of horizontal error. As with other files, the DEM must be well registered and in the same projection and datum as other files in the scene. Check the metadata accompanying the data to verify the projection.

(b) The primary source of DEM data is digital USGS topographic maps and not satellite data. Spaceborne elevation data will be more readily available with the processing and public release of the Shuttle Radar Topography Mission (SRTM) data. Some of this data is currently available through the Jet Propulsion Laboratory (<http://www.jpl.nasa.gov/srtm/>) and USGS EROS Data Center (<http://srtm.usgs.gov/index.html>).

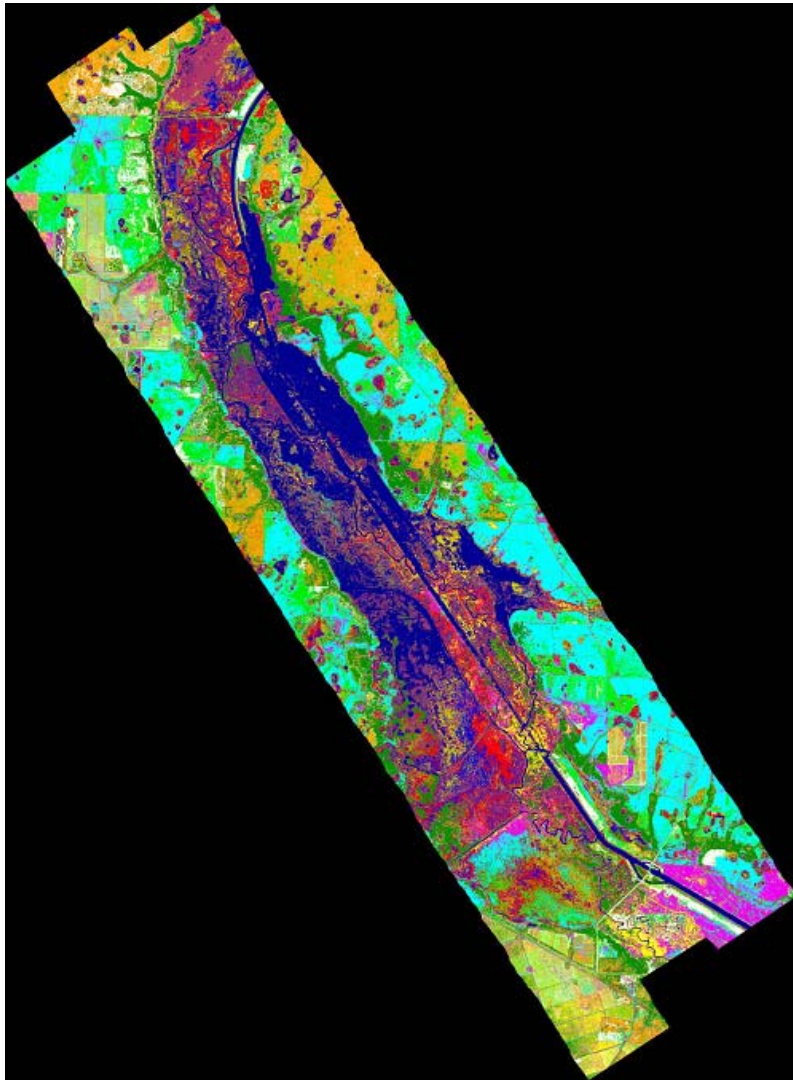


**Figure 5-24. Digital elevation model (DEM). The brightness values in this image represent elevation data. Dark pixels correspond to low elevations while the brightest pixels represent higher elevations. Taken from the NASA tutorial at [http://rst.gsfc.nasa.gov/Sect11/Sect11\\_5.html](http://rst.gsfc.nasa.gov/Sect11/Sect11_5.html).**

(c) DEMs can be created for a study site with the use of a high resolution raster topographic map. The method involved in creating a DEM is fairly advanced; see <http://spatialnews.geocomm.com/features/childs3/> for information on getting starting in DEM production.

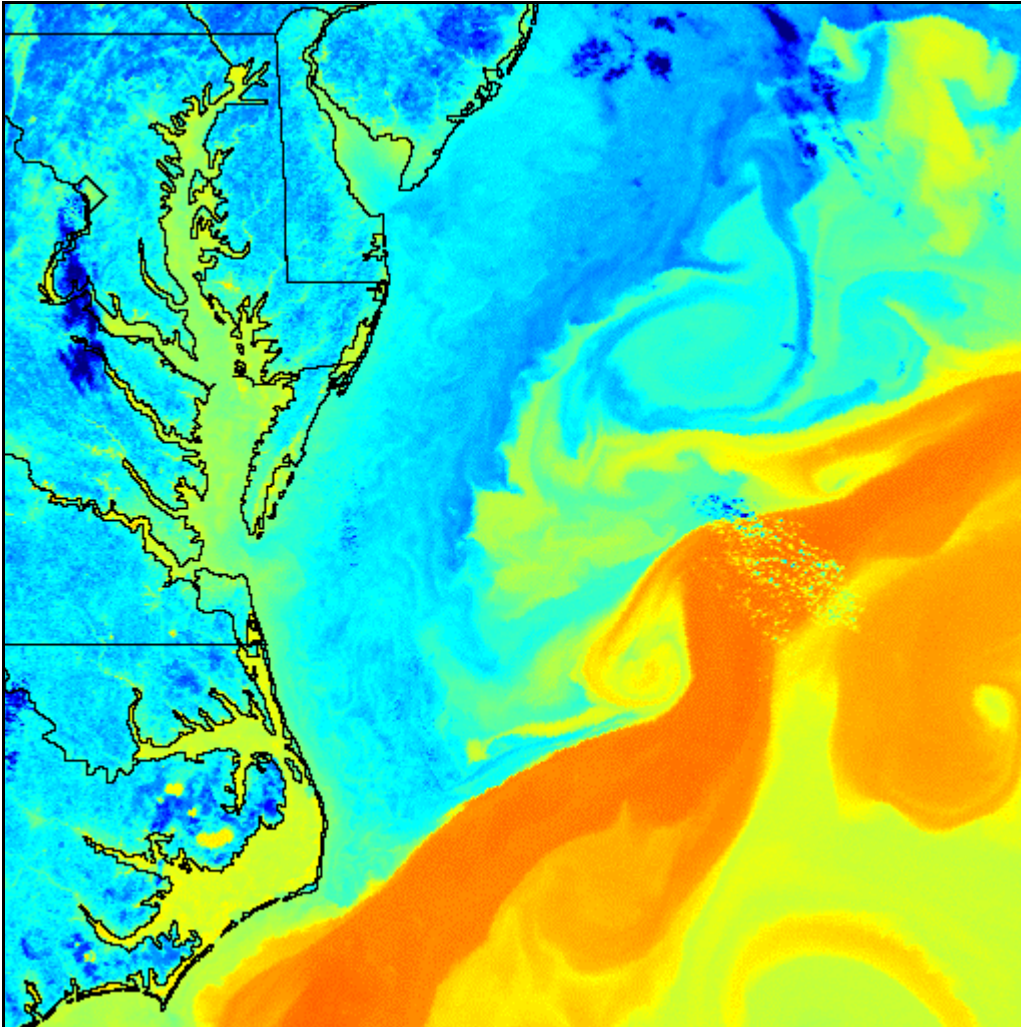
(4) *Advanced Methods in Image Processing.* Remote sensing software facilitates a number of advanced image processing methods. These advanced methods include the processing of hyperspectral data, thermal data, radar data, spectral library development, and inter-software programming.

(a) *Hyperspectral Data.* Hyperspectral image processing techniques manage narrow, continuous bands of spectral data. Many hyperspectral systems maintain over 200 bands of spectral data. The narrow bands, also known as channels, provide a high level of detail and resolution. This high resolution facilitates the identification of specific objects, thereby improving classification (Figure 5-24). The advantage of hyperspectral imaging lies in its ability to distinguish individual objects that would be otherwise grouped in broadband multi-spectra imagery. Narrow bands are particularly useful for mapping resources such as crop and mineral types. The narrow, nearly continuous bands create large data sets, which require advance software and hardware to store and manipulate the data.



**Figure 5-25. Hyperspectral classification image of the Kissimmee River in Florida (Image created by Lowe Engineers - LLC and SAIC, 2003). Classifications of 28 vegetation communities are based on a supervised classification.**

(b) *Thermal Data.* Thermal image processing techniques are used to image objects by the analysis of their emitted energy (Figure 5-26). The thermal band wavelength ranges are primarily 8 to 14  $\mu\text{m}$  and 3 to 5  $\mu\text{m}$ . The analysis of thermal data is typically used in projects that evaluate surface temperatures, such as oceans and ice sheets, volcano studies, and the emission of heat from man-made objects (e.g., pipelines).



**Figure 5-26. Close-up of the Atlantic Gulf Stream. Ocean temperature and current mapping was performed with AVHRR thermal data. The temperatures have been classified and color-coded. Yellow = water 23°C (73°F), green = 14°C (57°F), blue = 5°C (41°F). Taken from <http://www.osdpd.noaa.gov/PSB/EPS/EPS.html>.**

(c) *Radar.* Radar (radio detection and ranging) systems are able to penetrate cloud cover in certain wavelengths. This technology is useful for imaging day or night surface features during periods of intense cloud cover, such as storms, smoke from fire, or sand and dust storms (Figure 5-27).



**Figure 5-27. Radarsat image, pixel resolution equals 10 m. Image is centered over the Illinois River (upper left), Mississippi River (large channel in center), and the Missouri River (smaller channel in center. Chapter 6 case study 3 details the analysis of this scene. Taken from Tracy (2003).**

*g. Customized Spectral Library.* Many software programs allow users to build and maintain a customized spectral library. This is done by importing spectra signatures from objects of interest and can be applied to identify unknown objects in an image.

*h. Internal Programming.*

(1) Image processing software allows users to develop computing techniques and unique image displays by programming from within the software package. Programming gives the user flexibility in image manipulation and information extraction. The users' manual and online help menus are the best resources for information on how to program within particular software.

(2) New applications in image processing and analysis are rapidly being developed and incorporated into the field of remote sensing. Other advanced uses in image processing include the modification of standard methods to meet individual project needs and improving calibration methods. Go to [http://www.techexpo.com/WWW/opto-knowledge/IS\\_resources.html](http://www.techexpo.com/WWW/opto-knowledge/IS_resources.html) for more

information on advanced and specialized hardware and software and their applications.

i. *The Interpretation of Remotely Sensed Data.* There are four basic steps in processing a digital image: data acquisition, pre-processing, image display and enhancement, and information extraction. The first three steps have been introduced in this and previous chapters. This section focuses on information extraction and the techniques used by researchers to implement and successfully complete a remote sensing analysis. The successful completion of an analysis first begins with an assessment of the project needs. This initial assessment is critical and is discussed below.

(1) *Assessing Project Needs.* Initiating a remote sensing project will require a thorough understanding of the project goals and the limitations accompanying its resources. Projects should begin with an overview of the objectives, followed by plans for image processing and field data collection that best match the objectives.

(a) An understanding of the customer resources and needs will make all aspects of the project more efficient. Practicing good client communication throughout the project will be mutually beneficial. The customer may need to be educated on the subject of remote sensing to better understand how the analysis will meet their goals and to recognize how they can contribute to the project. This can prevent false expectations of the remotely sensed imagery while laying down the basis for decisions concerning contributions and responsibilities. Plan to discuss image processing, field data collection, assessment, and data delivery and support.

(b) The customer may already have the knowledge and resources needed for the project. Find out which organizations may be in partnership with the customer. Are there resources necessary for the project that can be provided by either? It is important to isolate the customer's ultimate objective and learn what his or her intermediate objectives may be. When assessing the objectives, keep in mind the image classification needed by the customer and the level of error they are willing to accept. Consider the following during the initial stages of a project:

- What are the objectives?
- Who is the customer and associated partners?
- Who are the end users?
- What is the final product?
- What classification system is needed?
- What are the resolution requirements?
- What is the source of image data?
- Does archive imagery exist?
- Is season important?
- What image processing software will be used? Is it adequate?
- What type of computer hardware is available? Is it adequate?
- Is there sufficient memory storage capacity for the new imagery?

- Are hardware and software upgrades needed? Who will finance upgrades?
- Are plotters/printers available for making hardcopy maps?
- Can the GIS import and process output map products?

(c) Field considerations:

- What are the ecosystem dynamics? What type of field data will be required?
- Will the field data be collected before, after, or during image acquisition?
- Who will be collecting the field data?
- What sampling methods will be employed?
- What field data analysis techniques will be required?
- Who will be responsible for GPS/survey control?
- Who will pay for the field data collection?
- Is the customer willing to help by providing new field data, existing field data, or local expertise?

(2) *Visualization Interpretation.*

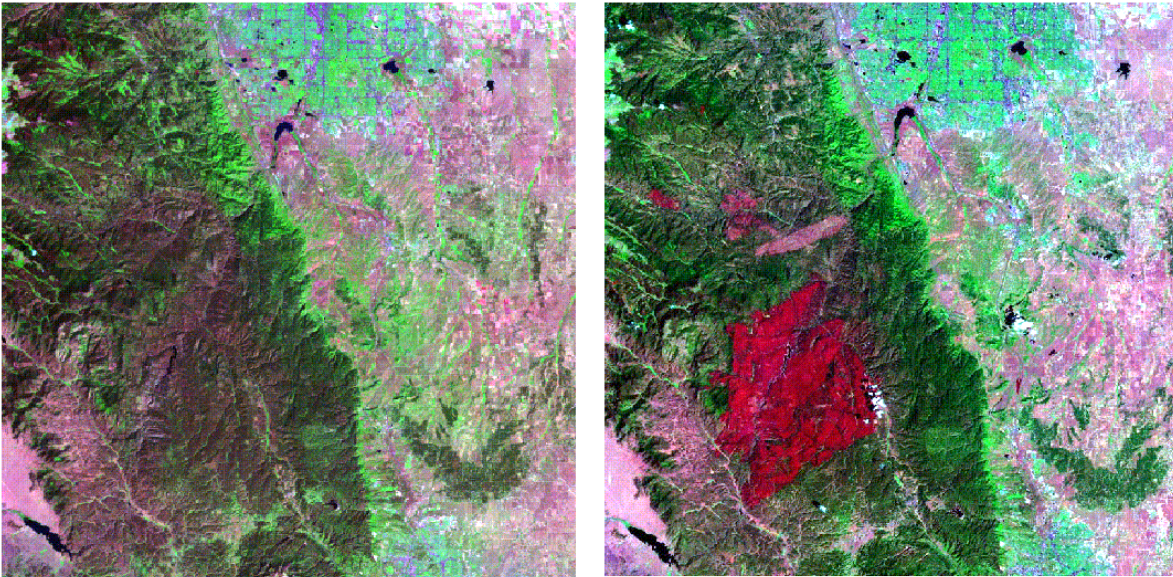
(a) Remotely sensed images are interpreted by visual and statistical analyses. The goal in visualization is to identify image elements by recognizing the relationship between pixels and groups of pixels and placing them in a meaningful context within their surroundings. Few computer programs are able to mimic the adroit human skill of visual interpretation. The extraction of visual information by a human analyst relies on image elements such as pixel tone and color, as well as association. These elements (discussed in Chapter 2) are best performed by the analyst; however, computer programs are being developed to accomplish these tasks.

(b) Humans are proficient at using ancillary data and personal knowledge in the interpretation of image data. A scientist is capable of examining images in a variety of views (gray scale, color composites, multiple images, and various enhancements) and in different scales (image magnification and reduction). This evaluation can be coupled with additional information such as maps, photos, and personal experience. The researcher can then judge the nature and importance of an object in the context of his or her own knowledge or can look to interdisciplinary fields to evaluate a phenomena or scene.

(3) *Information Extraction.* Images from one area of the United States will appear vastly different from other regions owing to variations in geology and biomes across the continent. The correct identification of objects and groups of objects in a scene comes easily with experience. Below is a brief review of the spectral characteristics of objects that commonly appear in images.

(a) *Vegetation.* Vegetation is distinguished from inorganic objects by its absorption of the red and blue portions of the visible spectrum. It has high reflectance in the green range and strong reflectance in the near infrared. Slight variability in the reflectance is ascribable to differences in vegetation morphology,

such as leaf shape, overall plant structure, and moisture content. The spacing or vegetation density and the type of soil adjacent to the plant will also create variations in the radiance and will lead to “pixel mixing.” Vegetation density is well defined by the near infrared wavelengths. Mid-infrared (1.5 to 1.75  $\mu\text{m}$ ) can be used as an indication of turgidity (amount of water) in plants, while plant stress can be determined by an analysis using thermal radiation. Field observations (ground truth) and multi-temporal analysis will help in the interpretation of plant characteristics and distributions for forest, grassland, and agricultural fields. See Figures 5-28 and 5-29.



**Figure 5-28. Forest fire assessment using Landsat imagery (Denver, Colorado).** Image on the left, courtesy of NASA, was collected in 1990; image on the right was collected in 2002 (taken from <http://landsat7.usgs.gov/gallery/detail/178/>). Healthy vegetation such as forests, lawns, and agricultural areas are depicted in shades of green. Burn scars in the 2002 image appear scarlet. Together these images can assist forest managers in evaluating extent and nature of the burned areas.

(b) *Exposed Rock (Bedrock).* Ground material such as bedrock, regolith (unconsolidated rock material), and soil can be distinguished from one another and distinguished from other objects in the scene. Exposed rock, particularly hydrothermally altered rock, has a strong reflectance in the mid-infrared region spanning 2.08 to 2.35  $\mu\text{m}$ . The red portion of the visible spectrum helps delineate geological boundaries, while the near infrared defines the land–water boundaries. Thermal infrared wavelengths are useful in hydrothermal studies. As discussed in earlier sections, band ratios such as band 7/band 5, band 5/band 3, and band 3/band 1 will highlight hydrous minerals, clay minerals, and minerals rich in ferrous iron respectively. See Figure 5-30.

(c) *Soil.* Soil is composed of loose, unconsolidated rock material combined with organic debris and living organisms, such as fungi, bacteria, plants, etc. Like exposed rock, the soil boundary is distinguished by high reflectance in

the red range of the spectrum. Near infrared wavelengths highlight differences between soil and crops. The thermal infrared region is helpful in determining moisture content in soil. See Figure 5-31.



**Figure 5-29. Landsat scene bands 5, 4, 2 (RGB).** This composite highlights healthy vegetation, which is indicated in the scene with bright red pixels. Taken from <http://imagers.gsfc.nasa.gov/ems/infrared.html>.



**Figure 5-30. ASTER (SWIR) image of a copper mine site in Nevada. Red/pink = kaolinite, green = limestones, and blue-gray = unaltered volcanics. Courtesy of NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team.**

(d) *Water (Water, Clouds, Snow, and Ice).* As previously mentioned, the near infrared defines the land–water boundaries. The transmittance of radiation by clear water peaks in the blue region of the spectrum. A ratio of band 5/band 2 is useful in delineating water from land pixels. Mid-infrared wavelengths in the 1.5- to 1.75-mm range distinguishes clouds, ice, and snow. See Figure 5-32.

(e) *Urban Settings.* Objects in an urban setting include man-made features, such as buildings, roads, and parks. The variations in the materials and size of the structure will greatly affect the spectral data in an urban scene. These features are well depicted in the visible range of the spectrum. Near infrared is also useful in distinguishing urban park areas. Urban development is well defined in false-color and true color aerial photographs, and in high resolution hyperspectral data. The thermal infrared range (10.5 to 11.5  $\mu\text{m}$ ) is another useful range owing to the high emittance of energy. A principal components analysis may aid in highlighting particular urban features. See Figure 5-33.

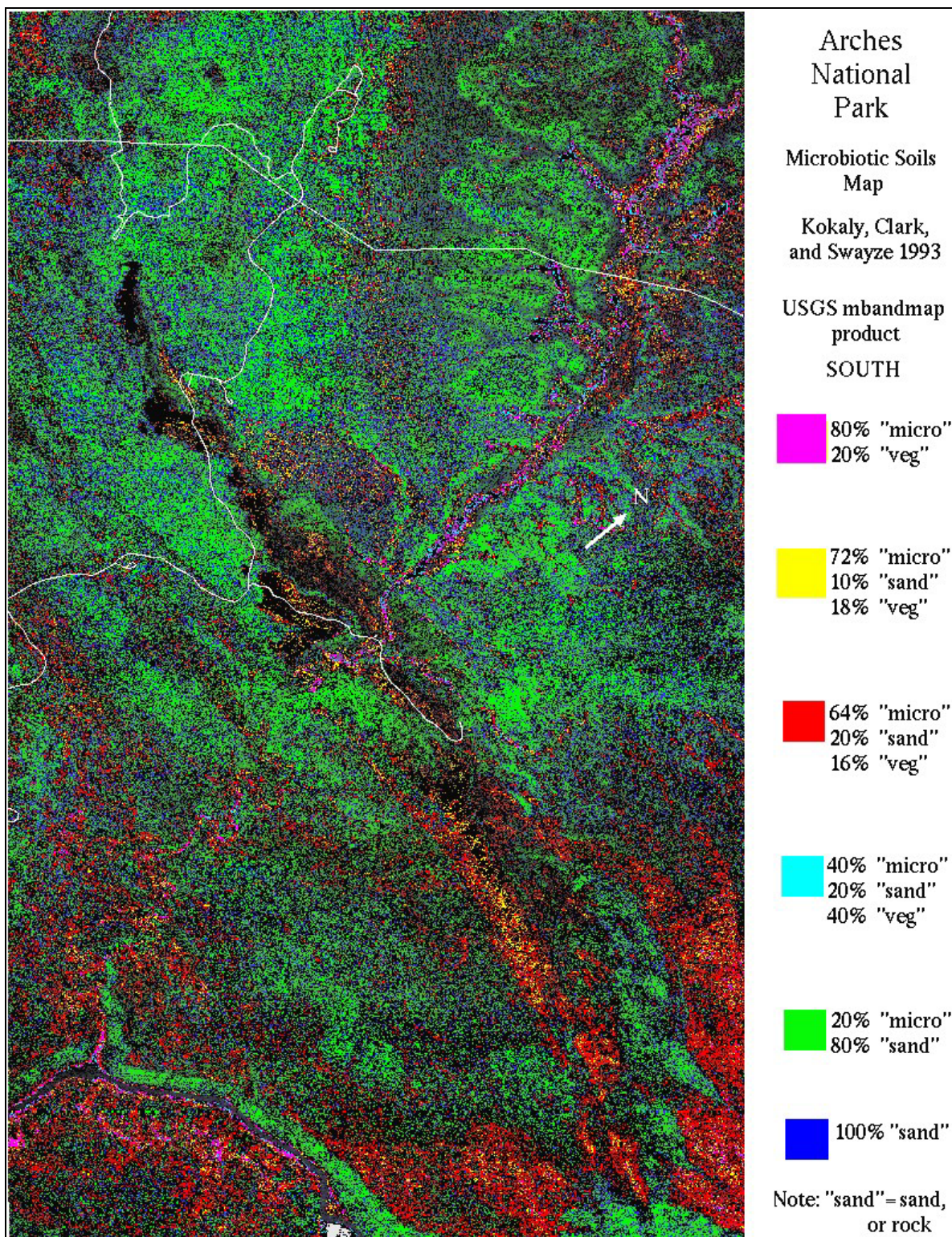


Figure 5-31. AVIRIS image, centered on Arches National Park, produced for the mapping of cryptogamic soil coverage in an arid environment. Taken from <http://speclab.cr.usgs.gov/PAPERS.arches.crypto.94/arches.crypto.dri.html>.

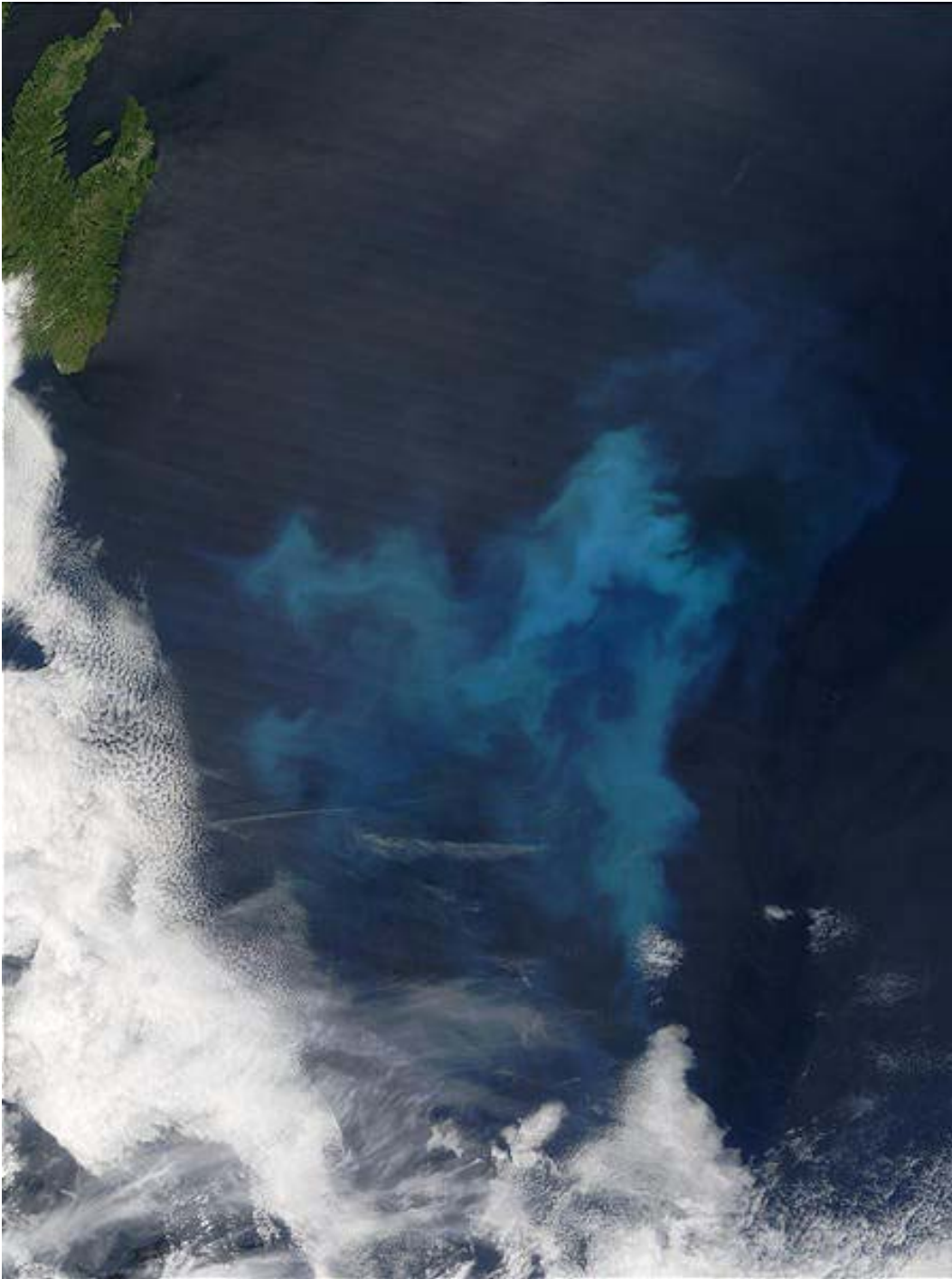


Figure 5-32. MODIS image of a plankton bloom in the Gulf of St. Lawrence near Newfoundland, Canada. Ground pixel size is 1 km. In this image, water and clouds are easily distinguishable from land (green pixels at top left of scene). Taken from <http://rapidfire.sci.gsfc.nasa.gov/gallery/?2003225-0813/Newfoundland.A2003225.1440.1km.jpg>.



**Figure 5-33. Orlando, Florida, imaged in 2000 by Landsat 7 ETM+ bands 4, 3, 2 (RGB). The small circular water bodies in this image denote the location of karst features. Karst topography presents a challenge to development in the Orlando area. Taken from <http://edcwww.cr.usgs.gov/earthshots/slow/Orlando/Orlando>**

(f) *Other Landscape Features.* A variety of unique landscape features are easily imaged with remote sensing. A few examples are illustrated below: Volcanic eruption (Figure 5-34), forest fires (Figure 5-35), abandoned ships (Figure 5-36), dust storm (Figure 5-37), oil fires (Figure 5-38), and flooding (Figure 5-39).

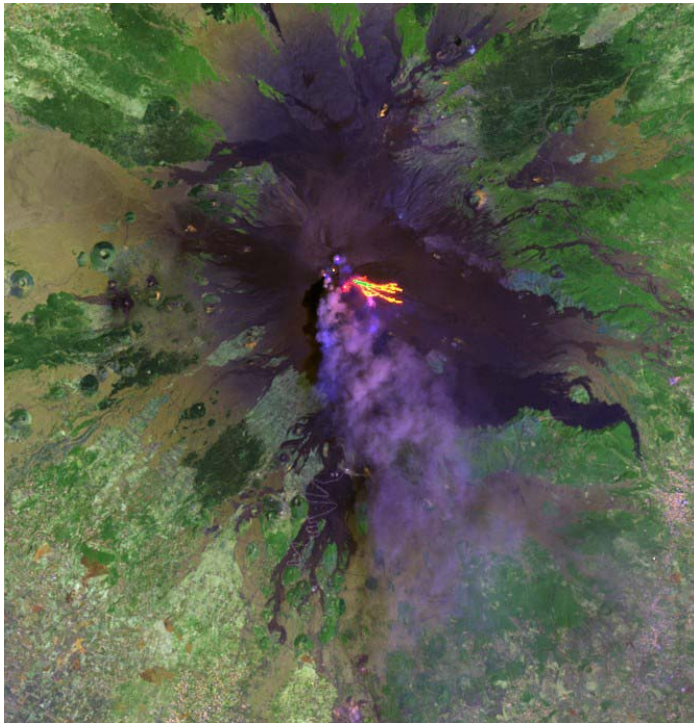


Figure 5-34. Landsat image of Mt. Etna eruption of July 2001. Bands 7, 5, 2 (RGB) reveal the lava flow (orange) and eruptive cloud (purple). Taken from <http://www.usgs.gov/volcanoes/etna/>.

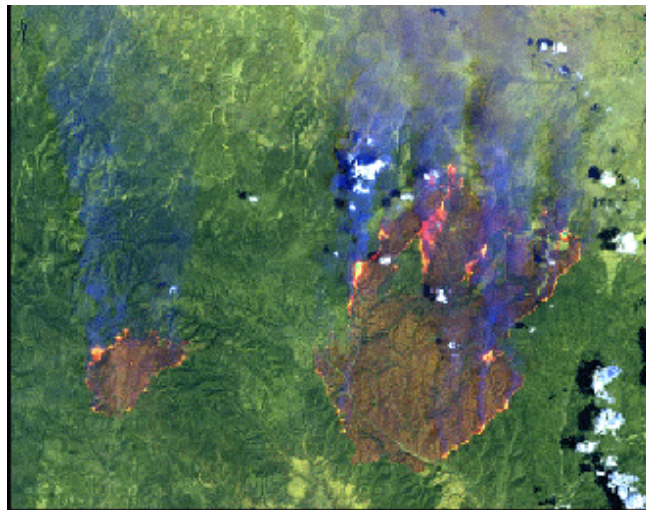


Figure 5-35. Forest Fires in Arizona may assist forest managers in fire-fighting strategies and prevention. Meteorologist also use such images to evaluate air quality. Image taken from <http://rst.gsfc.nasa.gov/Front/overview.html>.

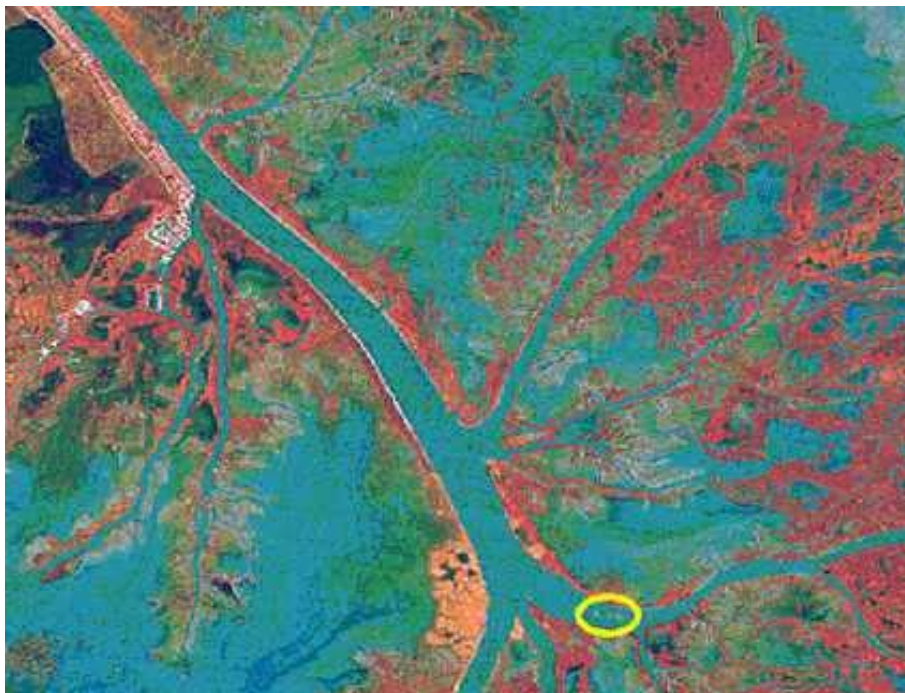


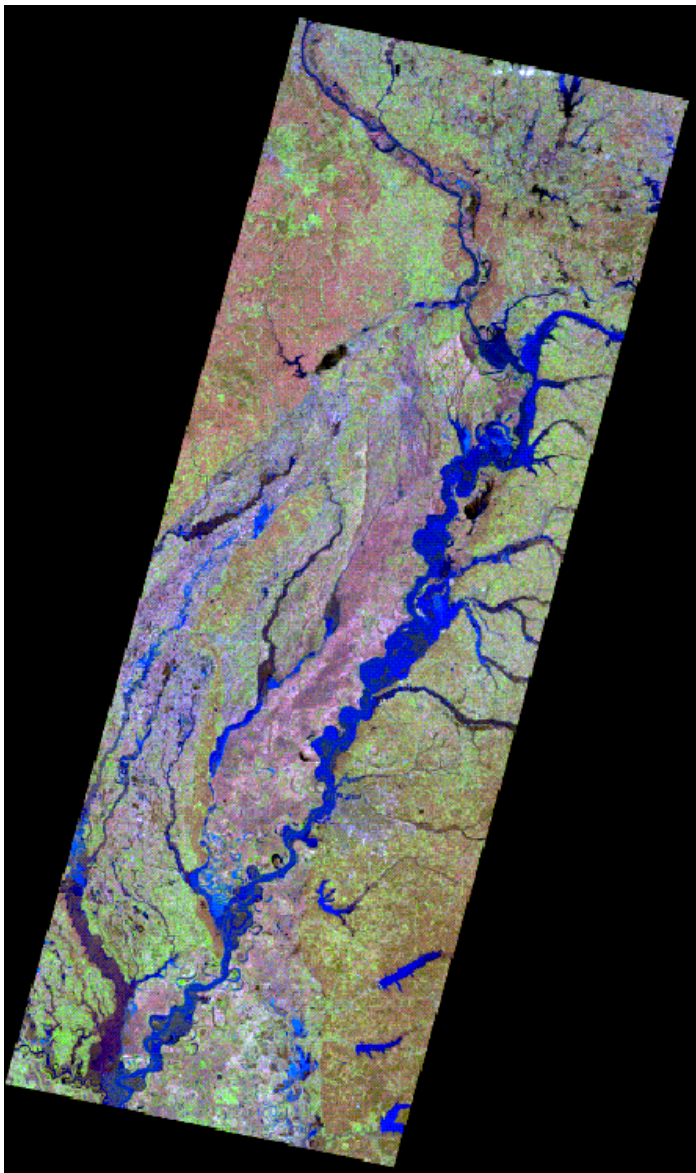
Figure 5-36. Grounded barges at the delta of the Mississippi River are indicated by the yellow circle. Taken from [http://www.esa.ssc.nasa.gov/rs\\_images\\_display.asp?name=prj\\_image\\_arcvip.5475.1999.101916538330.jpg&image\\_program=&image\\_type=&image\\_keywords=&offset=312&image\\_back=true](http://www.esa.ssc.nasa.gov/rs_images_display.asp?name=prj_image_arcvip.5475.1999.101916538330.jpg&image_program=&image_type=&image_keywords=&offset=312&image_back=true).



Figure 5-37. July 2001 Saharan dust storm over the Mediterranean. Taken from <http://rapidfire.sci.gsfc.nasa.gov/gallery/>.



Figure 5-38. Oil trench fires and accompanying black smoke plumes over Baghdad, Iraq (2003). This image was acquired by Landsat 7 bands 3, 2, 1 (RGB). Urban areas are gray, while the agricultural areas appear green. Taken from <http://landsat7.usgs.gov/gallery/detail/220/>.



**Figure 5-39. The mosaic of three Landsat images displays flooding along the Mississippi River, March 1997.**

*j. Statistical Analysis and Accuracy Assessment.* Accuracy assessment means the correctness or reliability in the data. Error is inherent in all remote sensing data. It is important to establish an acceptable level of error and to work within the resolution of the image. Working within the means of the resolution of an image is important for maintaining the desired accuracy. Attempting to extract information from an image for which objects are not clearly resolvable will likely lead to incorrect assumptions. Error can be introduced during acquisition by the sensor and while performing geometric and radiometric correction and image enhancement processes. Another major source of error lies in the misidentification and misinterpretation of pixels and groups of pixels and their classification.

(1) *Resolution and RMS (Root Mean Squared)*. Some errors are simple to quantify. For instance, the image pixel in a TM image represents the average radiance from a 30- × 30-m area on the ground. So, measurements within a TM scene will only be accurate to within 30 m. Positional accuracy may be established by a comparison with a standard datum giving an absolute uncertainty value. The RMS (root mean squared) error is automatically calculated during image rectification. This error can be improved while designating GCPs (Ground Control Points; see Paragraph 5-17).

(2) *Overall Accuracy*. Overall accuracy can be established with “Ground truth.” Ground truth is site-specific and measures the accuracy by sampling a number of areas throughout a scene. Overall accuracy of an image is then calculated by modeling the difference between the observed pixel DN signature and known object on the ground.

(3) *Error Matrices*. Assessing classification error is more involved. Solving for this type of error requires a numerical statistical analysis. Some software incorporates accuracy assessment within the classification function. For instance, classification error assessment compares an image classification matrix with a reference matrix. See Paragraph 5-20d(4) for information on classification accuracy. In this type of assessment, the reference data are assumed correct. Pixels are assessed in terms of their mistaken inclusion or exclusion from an object class; this is known as commission and omission (see Congalton and Green, 1999). All known error should be noted and included in any assessment. Review Congalton and Green (1999) for further information on the practice of error assessment.

*k. Presenting the Data*. Once a visual and statistical evaluation has been performed, the analysis must be presented in a manner that best communicates the information needed. The information may be presented as a hardcopy printout of the image or presented as a map (Figure 5-40). The information may also be displayed as a statistical database, which includes data tables and graphs. Knowledge of GIS, cartography, and spatial analysis is helpful in choosing and executing the manner in which the data will be presented. For instance, a number of GIS software programs are capable of displaying the image in a map format with a linked data set. Be sure to keep in mind the final product needed by the client.

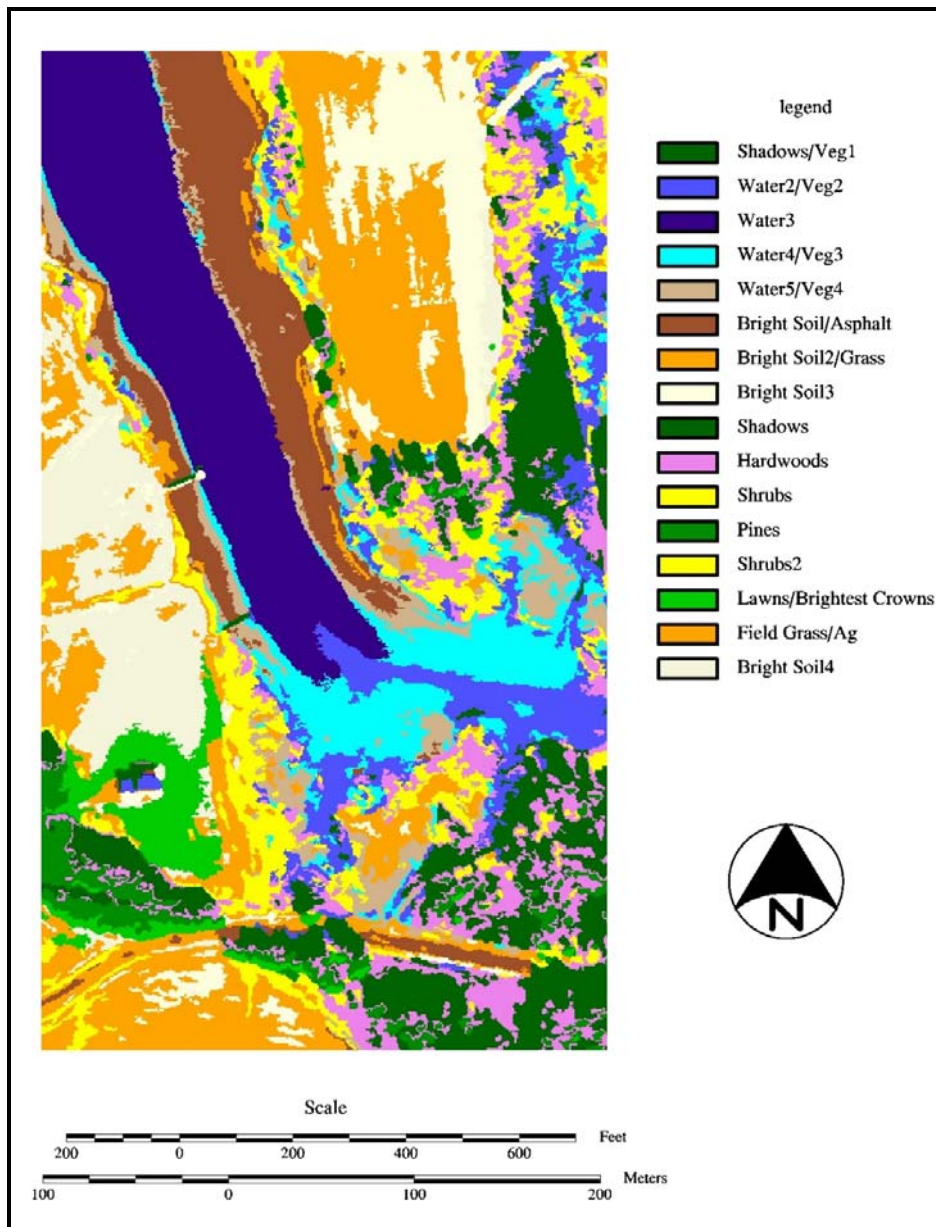


Figure 5-40. The final product may be displayed as a digital image or as a high quality hard copy. Taken from Campbell (2003).